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HISTORICAL NOTES ON GEM MINING.

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Pliny mourns the disfigurement of Mother Earth in gold and silver mining: "and for to seeke out gemmes and some little stones, we strike pits deep within the ground. Thus wee plucke the very heart-strings out of her and all to weire on our finger, one gemme or pretious stone, to fulfill our pleasure and desire. How many hands are worne with digging and delving, that one joint of our finger might shine againe. Surely if there were any devils or infernal spirits beneath, ere this time verily these mines for to feed covetousness and rowt would have brought them up above ground." The Historie of the World, commonly called the Natural Historie of C. Plinius Secundus. Philemon Holland Translation, vol. 1, p. 30, London, 1661.

INTRODUCTION.

Advance in the technical sciences would have been impossible without mining, since mechanical development is dependent upon the utilization of the metals and minerals concealed within the earth. History of civilization has therefore as a fundamental element the history of mining, and this paper presents some historical notes on the oldest form of mining, that of gems and decorative stones.

Paleolithic man knew nothing of metals, but between 100,000 B.C. and 7,000 B.C. used about fourteen different varieties of semi-precious and decorative stones—chalcedony, quartz and rock crystal, serpentine, obsidian, pyrite, jasper, steatite, amber, jadeite, calcite, amethyst, and fluorspar (see Table I.), while about the

[1] Presidential address 1930, Society of Economic Geologists.

time Neolithic man became acquainted with the earliest known metals (gold and copper) and with rudimentary agriculture and crude pottery making, nephrite, chloromelanite, sillimanite, and turquoise were added to the list. We might mention that when early man first found pebbles of native gold and copper, he shaped them much as he did stones and was ignorant that they were fusible. While in calling precious stones "the flowers of the mineral kingdom" [2] the gentle Abbé Haüy did not plagiarize the words of the men of the Stone Age, the latter were not less attracted by their beauty and utility. That they were surprisingly keen prospectors is evidenced by the fact that Neolithic man in Brittany rather commonly used callainite, as an ornament, yet the source of this mineral is as yet unknown to our French confréres. Strangely enough the closely related mineral, utahlite, was similarly used by the ancient Pueblo inhabitants of Utah.

The man of the Stone Age of Europe largely depended on stream gravels and residual deposits for his semi-precious stones, although he, doubtless, like the American Indian and the much less intelligent Andaman Islander, did some hard rock mining. Indeed the Egyptians carried on extensive operations at the Sinai peninsula turquoise mines with no other than stone tools until about 2,000 B.C. These were the first large mining operations, and were begun more than 5,100 years ago. For over 2,000 years those royal mining adventurers, the pharaohs, despatched to the mines large expeditions consisting of high officials, a few engineers and prospectors, several thousand laborers and an adequate military escort. The resulting stopes and galleries were extensive and the output large. The steles found at the mines give many touches of mining life, startingly modern to the engineer, for example, the name of the chief medical officer, stopes named after shift bosses, leasing contracts, and the defeat of attacking bands of Bedouin.[3] The lapis lazuli mines of Afghanistan may well be equally old. Thus for over 5,000 years, large

[2] Compare the Uralian lapidary's generic term of tzvetnie kameni (*tzvet*, flower, *kamen*, stone) for his material. (A. Erman, Travels in Siberia, vol. I., page 211, Phila., 1850.)

[3] S. H. Ball: Eng. and Min. Jour., vol. 123, pp. 483–5, March 19, 1927.

gem mining operations have existed and from gem mining its younger brother, metal mining, learned the trade.

TIME WHEN STONES BECAME KNOWN TO MAN.

Table I. lists the precious and decorative stones in the order in which they became known to man:

TABLE 1.

SHOWING TIME WHEN PRECIOUS AND DECORATIVE STONES ARE KNOWN FIRST TO HAVE BEEN USED.

100,000–75,000 B.C.* *CHALCEDONY.* Chellean from Torralba, Spain: also Dune Dwellers of Mongolia: Egyptian pre-dynastic.

100,000–75,000 B.C. *QUARTZ.* European Chellean and Acheulean at Salamanca, Spain, (Rock Crystal: Solutrean, Spain: also Swiss Lake Dwellers: pre-Sumerian: Egyptian pre-dynastic).

100,000–75,000 B.C. *JASPER.* European Chellean: also Aurignacian of Grimaldi, Italy: also Dune Dwellers of Mongolia: Swiss Cave Dwellers: also Egyptian and Mesopotamian pre-historic.

75,000–40,000 B.C. *SERPENTINE.* Acheulean: also late Mousterian, Castile, Spain: widely used by European Neolithic man.

50,000–25,000 B.C. *OBSIDIAN.* Mousterian of Transcaucasia: also Magdalenian of Bavaria: Swiss Lake Dwellers: Mesopotamian Marsh-dwellers.

PYRITE. Mousterian man and Swiss Lake Dwellers made fire with it: also English barrows; described by Theophrastus (315 B.C.).

STEATITE. Aurignacian of Grimaldi, Italy: also Egyptian pre-dynastic (prior to 3,400 B.C.): Mesopotamia (3,200 B.C.). Indus Valley (3,300–2,700 B.C.).

AMBER. Aurignacian (Wildscheuer Cave, Germany): also Solutrean (Spain): Magdalenian (Hautes-Pyrenées): Neolithic (Denmark and Sweden): Mycenae, 1,600–1,500 B.C.

About 22,000 B.C. *JADEITE.* Middle Aurignacian (Wildscheuer Cave, Germany): also Swiss Lake Dwellers, 7,000 B.C.: Sumerian, 3,500–3,000 B.C.; Maya, 50 A.D.

About 20,000–16,000 B.C. *CALCITE.* Solutrean (Cave of Gourdan, France); also Neolithic.

About 20,000–16,000 B.C. *AMETHYST.* Solutrean (France): also Neolithic of Europe: also Egyptian pre-dynastic.

About 20,000–16,000 B.C. *FLUORSPAR.* Solutrean (France): also Magdalenian (Belgium): Roman, about 1 A.D.

About 20,000–16,000 B.C. *AGATE.* Solutrean (France): also Egyptian pre-dynastic (before 3,400 B.C.): Sumerian (3,000 B.C. or earlier).

JET. Early Magdalenian (Thayman, Switzerland): also Neolithic (Pyrenees and Great Britain): known to Thales, 600 B.C.

20,000–7,000 B.C. *NEPHRITE.* Early Swiss Lake Dwellers: also Chinese, 2,284 B.C.: Maya, 100 B.C.

CHLOROMELANITE. Early Swiss Lake Dwellers: also French dolmens.

7,000–4,000 B.C. *SILLIMANITE.* Neolithic (France).

7,000–2,000 B.C. *TURQUOISE.* Neolithic (Spain), also Egyptian pre-dynastic (before 3,400 B.C.).

4,400 B.C. or Earlier. *HEMATITE.* Neolithic (Knossos, Crete): also Egyptian pre-dynastic (3,500 B.C. or earlier): Sumerian (3,000 B.C.).

Prior to 3,500 B.C. *ALABASTER.* Pre-Sumerian: also Egyptian pre-dynastic: dolmens of Brittany and Denmark: Indus Valley, 3,300–2,700 B.C.

CARNELIAN. Pre-Sumerian: also Egyptian pre-dynastic: Neolithic man of Sudan: Indus Valley 3,300–2,700 B.C. Anau Culture II.

* Paleolithic and Neolithic Chronology follows that of Henry F. Osborn in "Men of the Stone Age": Egyptian, that of J. H. Breasted.

TABLE I.—*Continued.*

LAPIS LAZULI. Ur: also Egyptian pre-dynastic: also Cretan 2,000–1,800 B.C. Anau Culture II.

SMOKY QUARTZ. Sumerian: also Egyptian pre-dynastic.

Prior to 3,400 B.C. *BERYL.* Egyptian pre-dynastic: also Cretan 2,200–1,800 B.C.; Babylonian 1,780–1,200 B.C.

CHRYSOCOLLA. Egyptian pre-dynastic.

GARNET. Egyptian pre-dynastic: also Sumerian, 2,350 B.C.: Bronze Age, Sweden (2,000–1,000 B.C.).

MALACHITE. Egyptian pre-dynastic: also Babylonian 1,780–1,203 B.C.

3,500–3,000 B.C. *WHITE FELDSPAR.* Pre-historic Mesopotamian.

3,200–3,000 B.C. *ONYX.* Ur: also Egyptian prior to 2,980 B.C.: Minoan (3,000–2,000 B.C.).

Prior to 2,980 B.C. *SARDONYX.* Egyptian: also Mycenean (1,600–1,400 B.C.): Assyrian 1,700–600 B.C.

2,980–2,750 B.C. *AMAZONSTONE.* Egyptian: Mesopotamia, prior to 731 B.C.

2,900–2,750 B.C. *AZURITE.* Egyptian.

2,500 B.C. *CALLAINITE.* Neolithic man of Brittany, Spain, and Portugal.

2,500–1,800 B.C. *AGALMATOLITE.* Babylonian.

2,000 B.C. *BLOODSTONE.* Babylonian.

2,000 B.C.–1,800 B.C. *EMERALD.* Egyptian: also Babylonian, 1,780–1,203: Siberia, 1,800–500 B.C.: Etruscan, 600–275 B.C.

2,445–1,350 B.C. *SCOLECITE.* Neolithic beads at Jebel Gule, between White and Blue Nile.

1,780–1,203 B.C. *MAGNESITE.* Babylonian.

1,600–1,400 B.C. *SARD.* Mycenean: Assyrian, 1,700–600 B.C.

1,580–1,350 B.C. *TOPAZ.* Egyptian.

1,580–1,350 B.C. *CHRYSOPRASE.* Egyptian.

1,580–1,350 B.C. *PERIDOT.* Egyptian: also Hellenistic, 300–100 B.C.

1,700–700 B.C. *SAPPHIRINE.* (Blue Chalcedony) Assyrian.

800–600 B.C. *ROSE QUARTZ.* Assyrian.

600 B.C. or earlier. *PLASMA.* Egyptian: also Phoenician, 1,000–500 B.C.

600–500 B.C. *MOSS AGATE.* Greek: Oriental seal, possibly Babylonian.

600–480 B.C. *ZIRCON.* Greek: also Etruscan, 600–275 B.C.

600–275 B.C. *SAPPHIRE.* Etruscan: also Greek (480–300 B.C.): Saite or Graeco-Roman period in Egypt (603 B.C. or later.)

600–275 B.C. *RUBY.* Etruscan: also Greek (480–300 B.C.).

500 B.C. *OPAL.* Described by Onamacritus: also Early Roman Empire.

480–300 B.C. *AQUAMARINE.* Greek (see Beryl above).

480 B.C. *DIAMOND.* Greek.

480–300 B.C. *NICOLO.* Greek.

400 B.C. *LAZULITE.* Oxus Treasure.

372–287 B.C. *BONE TURQUOISE.* Described by Theophrastus: also Early Roman Empire.

372–287 B.C. *PRASE.* Described by Theophrastus (372–287 B.C.) also Early Roman Empire.

280 B.C. *IOLITE.* Asoka's supposed throne found at Buddha Gaya: also Ptolemaic Period, Egypt.

About 50 B.C. *MEERSCHAUM.* Greek.

100–1 B.C. *BALAS RUBY.* Buddhist grave near Kabul: also about 1 B.C., Hindoo tope at Bīmāran: Early Roman Empire.

About 1 B.C. *SATINSPAR.* Arizona Basket Makers: probably described by Pliny.

56 A.D. *STAR SAPPHIRE.* (Doubtless Asteria of Pliny).

100 A.D. *AVENTURINE QUARTZ.* Roman Empire: Aztec.

About 100 A.D. *CAT'S EYE.* (Cymophane) Roman Empire: Rawlinson believes Phoenicians had it 500 B.C. or earlier.

MOONSTONE. Roman Empire.

SAPPHIRINE. (Silicate of alumina and magnesia): Roman (according to E. H. Warmington).

TABLE 1.—*Continued.*

CITRINE. Roman Empire.
51 B.C.–400 A.D. *BLUE SPINEL.* Roman—Anglo-Roman, England.
150 A.D.–400 A.D. *FUCHSITE.* Roman; also Maya.
150 A.D.–400 A.D. *SPINEL RUBY.* (See BALAS RUBY above). Late Roman Empire.
About 1,000 A.D. *MUSCOVITE.* Mound Builders of Mississippi Valley.
LABRADORITE. Red Paint people of Maine. Used in European jewellery, 16th Century. (Found 1770 in Labrador).
10th Century or Earlier. *MARCASITE.* Used by Mayas.
About 1,100 A.D. *SELENITE.* Cliff House culture, Arizona: probably known to Pliny, 56 A.D.
About 1,200 A.D. *VARISCITE.* Variety Utahlite used by Pueblos of Utah.
1419–44 A.D. *CAT'S EYE (QUARTZ).* Described by Nicolo di Conti.
15th Century or Earlier. *SODALITE.* Used by Peruvians in pre-Spanish time.
SCAPOLITE. Peruvian Indians.
SMITHSONITE. Used by Peruvians in pre-Spanish times.
LITHOMARGE. Aztecs.
AGATIZED WOOD. Pre-Columbian American Indian.
PECTOLITE. Alaskan Esquimaux.
1443–1533. *ATACAMITE.* Beads, Chile.
1443–1533. *BROCHANTITE.* Beads, Chile.
16th Century. *CYANITE.* Used in European jewelry (in time of James I, cut by German lapidary Cornellius).
1573. *TOURMALINE.* 1573, found in Brazil: identified by Dutch in precious stones brought from Ceylon, 1703: (described by De Laat and probably by Pliny).
1634. *CATLINITE.* Nicollet describes catlinite: doubtless quarried much earlier.
1719. *CHIASTOLITE.*
1758. *STAUROLITE.*
1775. *HYPERSTHENE.*
About 1777. *PREHNITE.* Col. Preh found it in South Africa.
1785. *EUCLASE.* Introduced into Europe from Brazil by Dombey.
1785. *DIOPTASE.* Found in Altyn Tube, Siberia, by Tashkent caravan leader.
1798. *ANDALUSITE.* Found in Andalusia, Spain, 1798: only occurs of gem quality in Brazilian gravel.
Late 18th Century. *SUNSTONE (Feldspar).* Used in Russian jewelry.
Late 18th Century. *RHODONITE.* Cut in Russia.
Early 19th Century. *IDOCRASE.* Cut at Naples.
1831. *ALEXANDRITE.* Found in Russia.
1832. *PHENACITE.* Discovered 1832, used as gem in Russia about 1860; only determined in 1883.
1832. *UVAROVITE.* Described by Hess, 1832.
1847. *CHLORASTROLITE.* Found in U. S. A.
1850. *GOLD QUARTZ.* Commonly used in California; also Apache Indians certainly by 1871.
About 1851. *DEMANTOID.* Found in Russia.
1866. *EPIDOTE.* Gem variety first found in Austrian Tyrol.
1867–8. *ZONOCHLORITE.* Found in U. S. A.
1870. *SPODUMENE.* (Clear yellow)—First reported from Brazil.
About 1870. *THOMSONITE.* Found in U. S. A.
1876. *TIGER EYE.* Found in South Africa.
About 1879. *ENSTATITE.* Gem variety found in South Africa.
1877. *HIDDENITE.* Found in U. S. A.
1886. *BERYLLONITE.* Found in U. S. A.
1902. *MORGANITE.* First produced in Madagascar.
1903. *KUNZITE.* Found in U. S. A.
1907. *BENITOITE.* Found in U. S. A.
1907. *DANBURITE.* Of gem quality produced in Madagascar (Min. of Madagascar, Lacroix, vol. II, p. 103.)
1911. *KORNERUPINE.* Of gem quality, produced in Madagascar (Min. of Madagascar, Lacroix, vol. II, p. 102.)

In a broad way I feel that the above table represents approximately the order in which the precious and semi-precious stones were known to man. Tourmaline, however, I am satisfied must have been imported into Rome with other gems from the Ceylon stream gravels, and while I know of no piece of Roman jewelry decorated with it, I believe I can recognize it among the "rubies and garnets" described by Pliny[4] in "lychnites" which when rubbed drew to itself straws and light bits of paper. It will be noted that certain minerals were only found of gem quality long after they were known as mineral species, for example gem epidote, only found in 1866 at Knappenwald, Saxony.

The stones first used were notable for their beautiful colors rather than their brilliancy and many of them were opaque. The superlatively precious stones—emerald, ruby, sapphire, and diamond—were first used from about 2,000 to 400 B.C. Indeed 1,800 years ago practically all of the important gems were in use.

As stated before, many precious and decorative stones were used before gold and copper, the earliest metals, and over 30 before silver and lead were known. Zinc was not recognized in Europe until 1509 A.D.; nickel was not isolated until 1751, and a number of metals used in alloys were unknown to our fathers' generation. In other words, the application of gems antedates in general that of metals.

THE AMERICAN INDIAN AS A GEM MINER.

We are not inclined to look upon the Indian of North and South America as a mineralogist and a prospector; he used, however, many semi-precious and decorative stones (Table 2). The list as presented is fairly complete for North and Central America but in South America, outside of Peru, could doubtless be appreciably extended. It can be said with considerable assurance that at the beginning of our era, or roughly 2000 years ago, the American Indian, applying the term in a broad sense, used the following precious and decorative stones: jadeite, pyrite, chalcedony, obsidian, calcite, satin spar, selenite, rock crystal.

[4] Natural History, book 37, ch. VI.

TABLE 2.

PRECIOUS AND DECORATIVE STONES KNOWN TO NORTH AND SOUTH AMERICAN INDIANS.

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PRECIOUS AND DECORATIVE STONES KNOWN TO NORTH AND SOUTH AMERICAN INDIANS.

Name.	Maya.	Aztec.	Other North American.	Peruvian.	Other Central and South American and West Indies.
Agalmatolite			Used		
Agate	Used	Used, also Zapotecs	Western Indians from Brit. Col. to Mexican border: oldest, Cliff House Culture	Used	Chili, Columbia, Panama, Guiana, Brazil
Agatized Wood	Used	Used	Oreg., Wyom., N. M., Ariz.: Earliest Basket Makers		
Alabaster (Calcite)	Used	Pre-Aztec, also Aztec	Late Basket Makers N. M., Ohio, N. Y. (Stalagonitic)		
Amazonstone	Used	Used	Cal.		Venezuela, Brazil
Amber		Common	Point Barrow Eskimos		Santo Domingo
Amethyst		Used	California islanders, Ga., Navajos, Ala.	Used	Montserrat, W. I.
Apatite			Pueblos.		
Azurite			Late Basket Makers N. M., Cliff House Culture, Ariz. Zuni		
Atacamite					Near Chuciquicamata, Chile, about 1443–1533
Aventurine Quartz		Aztec			
Beryl		Used	Lewiston, Idaho 1907		Brazil
Bloodstone		Used			Old Coclé culture Panama
Brochantite					Near Chuciquicamata, Chili, about 1443–1533
Calcite	Used		Widely used oldest late Basket Makers, (Ariz.) and "Mound-Builders"		Jamaica, W. I.
Carnelian	Used	Used	Pueblos and Georgia		Montserrat, W. I., Panama, Teironos of Colombian Coast

TABLE 2.—*Continued.*

Name.	Maya.	Aztec.	Other North American.	Peruvian.	Other Central and South American and West Indies.
Catlinite			Great Plains, Ga. and N. Y. Mound-Builders		
Chlorite					
Chloromelanite	Used	Used			
Chalcedony	1st Empire 200–300 A.D.	Used	South Western, Western, Pacific Coast, Mid-West and Southeastern Indians: earliest Late Basket Makers	Used	Montserrat, W. I., Porto Rico, W. I., Argentina
Chrysocolla					Bolivia, Chile
Chrysoprase				Used	
Diamonds *					?
Emerald	Reported	?		Used	Ecuador, Colombia; Brazil by barter
Feldspar (White)		Used			
Feldspar (Flesh-colored)			Pueblos		
Fluorite		Used	Pueblos: Mound-Builders of Mo.: also Southern Illinois: Posey Co. Ind.: Cal.	Used	
Fuchsite	Guatemala				
Garnet		Used	Mound-Builders, Ohio, Ariz.		
Gold Quartz			Ga: Apache 1871		
Hematite	Used	Used	Widely used, earliest Basket Makers	Used	Venezuela
Jadeite	Rio Graciosa tablet dated 50 A.D.; Costa Rica	Used, also Mexico, City, pre-Aztec; Mt. Alban; old Zapotican culture	Mound-Builders, (Ohio); Brit. Col., Alaskan Eskimos; Pueblos of Chihuahua		Brazil, Guianias, Trinidad, W. I., St. Kitts, W. I., Montserrat, W. I.
Jasper	Used	Used	Widely used, earliest Basket Makers		Brazil

* Richard F. Burton (The Highlands of Brazil, vol. II, p. 107) states "used, it is said, by the Indians as playthings for their children." In exceptional cases possible, but improbable.

TABLE 2.—*Continued.*

Other Central and

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Name.	Maya.	Aztec.	Other North American.	Peruvian.	Other Central and South American and West Indies.
Jet (including Cannel coal and lignite).....	Used	Used (also Toltec)	Pueblos, Mound Builders, Alaskan Eskimos: West Va.: Tenn.: earliest Basket Makers		Montserrat, W. I.
Labradorite.....			"Red Paint People" of Maine	Used	Montserrat, W. I.
Lapis Lazuli.....				Used	
Lazulite.....					
Lithomarge.....		Used			
Magnesite.....			Pueblo II of Nevada: California		
Malachite.....	Used	Common	Pueblo Indians, earliest Basket Makers	Used	
Marcasite.....	Used	Used	Texas	Used	
Mica.....			Mound Builders: N. Y. Va. N. C. Pueblos, Bering Strait Eskimos; Florida		
Moss Agate.....			Arizona		
Nephrite.....	Statue: State of Vera Cruz, dated 100 B.C.: Central Amer. 1st Empire 200–300 A.D.	Used	Indians and Eskimos from Puget Sound to Point Barrow		Brazil, Ecuador, Montserrat, W. I.
Obsidian.....		Commonly used by Pre-Aztecs and Aztecs	Mound Builders: widely west of Miss.; earliest Late Basket Makers	Used	Argentina, Colombia
Opal, fire.....	Quiché	Used	Brit. Col.		
Olivine.....			Pueblos, Navajos		
Pectolite.....			Point Barrow Eskimos, Brit. Col.		

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TABLE 2.—*Continued.*

Name.	Maya.	Aztec.	Other North American.	Peruvian.	Other Central and South American and West Indies.
Prase		Used			
Pyrite	Common	Common, also Toltecs	Cliff House Culture, Arizona; Eskimo	Used	
Quartz (including Rock Crystal)	Used	Common also pre-Aztec	Widely used earliest Late Basket Makers	Used	Montserrat, W. I., Colombia; Paraguay, Brazil, Guiana, Ecuador
Satin Spar			Pueblos, earliest Basket Makers		
Scapolite				Used	
Selenite			Pueblos, earliest Cliff House Culture		
Serpentine	Used	Used	Mound Builders, Ga., Tenn.; Cal., Alaskan Eskimos: Pueblos, earliest Basket Makers		
Sillimanite			Southwest	Used	Brazil
Smithsonite					
Smoky Quartz			Georgia and Navajos		
Soapstone (steatite)		Used	Widely used, Arctic Circle to Mexican border; earliest Mound Builders	Used	Brazil
Sodalite				Used	
Tourmaline			Calif. Ind.; not very old		
Turquoise	Used	Common	Pueblos: Nevada, Mississippi, and Plains Indians: Eskimos of Aleutian Islands: earliest Late Basket Makers	Used	Chili, Argentine, Bolivia, Montserrat, W. I.
Utahlite			Utah Pueblos		

jasper, jet, azurite, malachite, turquoise, hematite, alabaster, agate, agatized wood, bloodstone, nephrite and serpentine. By 1,000 A.D. or even earlier, the following had been added: amber, carnelian, chloromelanite, emerald, fluorspar, garnet, labradorite, magnesite, marcasite, mica, opal, soapstone and probably utahlite and also others.

Many of these stones were doubtless obtained from fragments of float and river gravels; such were the sources of jade in Alaska and on the benches of the Fraser River, the amber on the Alaskan coast and the delta of the Yukon, agatized wood and other quartz species of the Petrified Forest, Arizona, and the garnets of New Mexico. The Indian, however, did much quarrying, the open cuts particularly of turquoise and obsidian, being extensive. He also mined emerald (Colombia), catlinite (Pipestone, Minn.): soapstone (at many places from New England to Georgia, in the Pacific States, especially, Santa Catalina Island, and on Cumberland Sound): serpentine (Phillipsburg, N. J.): Mexican onyx (particularly in Puebla, Mex.): stalagmitic calcite (Wyandotte Cave, Ind.): jasper (eastern Penn.): mica and quartz (Appalachian region, especially No. Car.): magnesite (White Butte near Cache Creek, Cal.): and hematite (Marquette, Mich. and Iron Mt., Mo.).

The Indians also traded widely in gems and decorative stones: Minnesota catlinite was carried as far as New York and Georgia: the Moundbuilders had obsidian in quantity, probably obtaining it from the Yellowstone National Park: and mica from the Appalachian Mountains: New Mexican turquoise reached Mexico City, if not indeed the Maya cities, and Colombian emerald was so common in Peru that for at least two centuries after the Conquest it was known as Peruvian emerald. But the most interesting example of trade was the possession by the pre-Colombian Caribs, of the tiny island of Montserrat in the West Indies, of ornaments of amethyst, carnelian, jadeite, turquoise, rock crystal, chalcedony, lapis lazuli, nephrite and cannel coal.[5] These semi-precious stones are all foreign to the island and strongly suggest that for their raw material the local lapidaries were able to draw upon a number of different localities.

[5] Guide to the Museum of the American Indian, Heye Foundation, 1922, pp. 65 and 75.

TABLE III.

Chronology of Gem Mining.

B.C.

7,000 B.C. probably earlier. Amber gathered on Prussian Coast.
4,400 B.C. Obsidian produced in island of Melos.
Prior to 3,400 B.C. Turquoise mines of Sinai Peninsula worked (malachite, chrysocolla and hematite, by-products).
3,400 B.C. Badakhshan Lapis Lazuli mines probably worked, although first direct reference is that of Istakri (951 A.D.)
About 3,400 B.C. Pharaohs mined alabaster at Wady Gerrauî: about 2980 Kheops and his successors quarried it at Hâtnûbû.
Early Egyptians mined rock crystal north of Aswan.
Early Egyptians mined amethyst near Gebel Abu Diyeiba.
1,925 B.C. Emerald beryl mines at Jebel Zebara, Egypt, known to have been in operation; perhaps mining started earlier.
1,580–1,350 B.C. Mining of Olivine begins on Zebirget Island, Red Sea.
1,100 B.C. Jade mined in Shen-si province, China.
1,000–7,000 B.C. Sicilian amber produced.
Prior to 1,000 B.C. Amber produced on Lebanon coast by Phoenicians.
800–600 B.C. Probable beginning of diamond mining, India: an important industry by 600 A.D.
800–600 B.C. Ceylonese gem industry probably starts.
500 B.C. Arabian agate an article of commerce.
500–400 B.C. Probable beginning of agate mining, India.
400 B.C. Beryls produced in India.
371–266 B.C. Theophrastus states agates obtained from Achates River (present Drillo), Sicily.
300 B.C. or earlier. Topaz mines on Red Sea coast of Egypt operated.
About 150 B.C. Khotan, Turkestan, jade mines opened.
About 50 B.C. Meerschaum mined by Greeks at Eskehehr, Asia Minor: pipe making started 1,723 A.D.
Prior to Christian Era: Garnets produced in India.
Prior to Christian Era: Swiss Alps furnish rock crystal to Romans.

1 A.D.–1,000 A.D.

1 A.D. Nishapur (Persia) turquoise mine probably opened up; perhaps, however, not until some years previous to 880 A.D.
100 A.D. Salzburg Alps emerald mines probably found.
100 A.D. Hungarian opal deposits probably worked: certainly operating 1,400 A.D.
100 A.D. Burmese amber being produced at this date or earlier.
200–400 A.D. Fluorspar doubtless by-product of Derbyshire (England) lead mining by Romans: Derbyshire cutting industry started 1,765 A.D.
Romans operate jet mines in Britain: 658–680 A.D. Whitby (England) jet mentioned by Caedmon.
714 A.D. Rock crystal being produced, Province of Mutsu, Japan.
750–950 A.D. Badakhshan spinel-ruby mines opened.
600–1,000 A.D. Probable date discovery Borneo diamond mines.
9th and 10th centuries. Madagascar rock crystal an article of Arabian commerce: Admiral Houtman in 1595 found it in Antongil Bay.

1,000–1,600 A.D.

About 1,000 A.D. Los Cerillos (New Mex.) mine or others in the S. W. were operating; some mining of southwest turquoise probable by 1 A.D.
1,000 A.D. or earlier. Colombian Indians had emeralds; hence Muzo or other Colombian mines probably already opened up.
13th Century. Yunnan trader brings first Burmese jade into China. Only found in place in the 1870's.
About 1400. Idar-Oberstein (Germany) agate industry established.

TABLE III.—*Continued.*

About 1400. Burma ruby mines known: may have been discovered 800 years earlier; Shan ruler transfers them to Burma, 1597: Ruby Mines Ltd. operated, 1889–1925.

Prior to 1492.

Aztecs mined alabaster near Tecali.
Aztecs mined obsidian at Sierra de las Navajas: mines probably antedate this year several centuries.
Amber gathered on coast of Mexico and Santo Domingo.
Aztecs mined opals.

About 1500. Bohemian garnet industry established.
1573. "Brazilian emeralds" (Tourmalines) first found; mining began 1770.
1576. Agates of Uruguay-Brazilian frontier known.
About 1590. Zircon mined at Puy de Valai, France, sold as "Diamond of France."

1,600–1,800 A.D.

1618–26. Fray de Zárate Salmeron mentions New Mexican garnet "mines": garnets used by Indians centuries ago.
About 1620. Probable discovery of Siamese sapphire-ruby mines.
1640. Lallemont describes the beauty of Lake Superior amethysts.
1642. Nephrite (jade) used by Maoris when Tasman discovered New Zealand.
1643. John Nieuhoff reports rock crystal produced in Brazil.
1668. Beryl-Topaz deposits of Mursinka district, Urals found.
1673. Father Marquette smoked a "calumet" of catlinite; initial quarrying by Indians earlier.
1699 or earlier. Altai beryl mines opened up.
1703. Ceylonese tourmaline recognized by Dutch children.
1710. Mountaineers discover Mallavilly diamond mines, India.
1718. Tourmaline of Maingnin, Burma, first worked by Chinese.
1720. Presence of lapis-lazuli in Chili mentioned by Europeans. This or another source known to pre-Spanish S. A. Indians.
Important Brazilian diamond fields discovered. First exports 1727.
1727. Amethyst exports from Brazil began.
1735. Nephrite of Jordansmühl, Silesia described by Linnaeus.
1737. Saxon topaz mines working: beginning probably earlier.
1740. Chrysoprase at Gläsendorf, Silesia, discovered.
1746. Diamonds found in Matto Grosso, Brazil.
About 1750. Spaniards open up amethyst mine at Auvergne, France.
1753. Sapphires of Expailly, France, mined by peasants.
1755. Diamonds found at Propria, Bahia, Brazil; rediscovered in Bahia 1821.
1760. Topaz mines of Ouro Preto (Brazil) found. Uncut topazes sold at Rio two years earlier.
1770. Labradorite discovered on St. Pauls Island, Labrador.
1771. Grão Mogol (Minas Geraes, Brazil) deposits found.
1783. Col. Preh brought prehnite to Europe from Cape of Good Hope.
1785. Amazonstone discovered near Troiska fortress, Urals.
1790. Ural malachite mines producing heavily.
Prior to 1798. Tourmaline discovered at Sarapulka, Urals.
About 1799. Ural amethyst deposits found.
Prior to 1799. Cutting of idocrase from Mt. Vesuvius a flourishing Neopolitan industry.
Sunstone (oligoclase) obtained from Cedlovatoi Island, near Archangel.

1,801–1,900 A.D.

1802. Del Rio describes fire opal of Zimapan, Mexico.
About 1805. Amber found in Russia: perhaps known long before, as it occurs in "Scythian" mounds and Pliny gives Scythia as a source.
Sunstone found at Lake Baikal, breaking price of gem.

TABLE III.—*Continued.*

1805. Chrysoberyl export from Brazil began at least by that year.
1808. Lake Baikal lapis lazuli first mentioned.
1810. Euclase of gem quality first found in Brazil.
1817. Prior to this date Hindoo lapidaries cut cyanite.
1820. Mt. Mica (Me) tourmalines found in late fall.
1825. Miass topaz mines operated; were found in 17th century; zircon found about 1825.
1827. Agates of Southern Brazil rediscovered and mining began.
1828. First Russian mining of rhodonite near Ekaterinburg.
1829, July 4th. First Russian diamond found at Bissersk placer, Urals.
1830. Ural emerald mines discovered.
Large quantities of Brazilian citrine appear on market.
1831. Alexandrite first discovered in Urals.
1833–4. São Joa de Chapoda, Brazil, diamond mine found by old slave woman.
1835. Opal found near Queratero, Mexico, but only systematically worked in 1870.
1839–41. Chapada, Bahia, field first worked by slave familiar with Minas Geraes deposits.
1843. First American diamond found Brindletown Creek, Burke Co., N. C., by Dr. M. F. Stephenson.
Von Leonhard describes Honduras opals, previously discovered; probably known to pre-Colombian Indians.
1850. Topaz locality of Transbaikalia, Siberia, found in early fifties.
Gold Quartz becomes common ornamental stone in California.
Sunstone found at Tvedestrand, Norway.
First California diamond found.
1851. First Australian sapphire found, at Apple Gully, N. S. W.
About 1851. Demantoid (Garnet) found in Urals.
1851. First Australian diamond discovered at Reedy Creek, New South Wales, by E. H. Hargraves.
1858. Gem euclase found in river Sanarka, Urals.
1860. Opal at Koja Dagh, Anatolia, found by Englishman.
1865. Sapphires recognized in Montana placers: 1893, mining began: 1895, stones found in place.
Sapphires found near Chantabun, Siam.
1866. First gem epidote found in Austrian Tyrol.
1867. First South African diamond recognized: March, 1869, Star of South Africa, world's most important diamond, found: 1870, first production at Pneils: 1870, Jagersfontein, first pipe mine, located.
1868. Zonochlorite discovered, north shore of Lake Superior.
1870. "Cape rubies" (garnets) a by-product of South African pipe diamond mining
1872. First Australian opal found.
First Californian tourmalines found near Riverside.
About 1873. Garnets found in Tanganyika Territory.
1873. European first acquainted with presence of diamonds in Shantung Province, China.
1875. Pikes Peak (Colo.) amazonstone found.
Prospectors discover meerschaum in Grant Co. N. M.
1876. April 1st, Anakie Queensland sapphire found: 1881, mining begins: 1891, scale of operations markedly increased.
Tiger eye found in Griqualand, South Africa.
1877. Topaz from Omi Province, Japan, first recognized.
Transparent yellow spodumene from Brazil first described.
Hiddenite (green spodumene) first found in North Carolina.
1878. First Queensland opal mine floated, though discovery was earlier. Better material found in 1880.
About 1878. Rose quartz first mined in Black Hills, South Dakota; only actively from 1902 on.
About 1880. John Coleman re-discovered Burro Mt., N. M., turquoise deposits formerly worked by Indians.

TABLE III.—*Continued.*

In 1880. Charcoal maker finds peridot at Poldnevnaya, Urals.
1881. Cannavieras (Bahia) diamond district discovered by forester with experience in other Brazilian diamond fields.
1882. F. R. Mallet identifies Kashmir sapphires, and mines opened; exhausted by 1905.
1885. Burmese hunters recognize sapphires of Phailin Cambodia and mining begins
1886. Nephrite found by Lieut. Stoney in Jade Mts., Alaska.
1888. First British Guiana diamond found: 1890, production began.
1889. Tourmaline found at Mt. Bity, Madagascar.
White Cliffs, New South Wales, opal field found.
1890. Emmaville (N. S. W.) emeralds found in place, although had been won from gravels for some time previously.
Fire opal found, Whelan, Washington.
Chieng-Kawng, northern Siam, sapphire mines discovered by Burmese gem diggers.
1893. Rhodolite (garnet) found in Macon Co., No. Car.
1894. Variscite first mined in Utah Co., Utah.
1897. Nephrite found in place near Lake Baikal by L. von Jascewski, Russian geologist.

1900 to Date.

About 1900. Nephrite found in place by A. Dieseldorff in New Zealand.
1902. Kunzite (lilac spodumene) found in California.
Morganite (pink beryl) first produced in Madagascar.
Premier diamond mine, South Africa, discovered by T. M. Cullinan; starts production in 1903.
1905. First diamond found in Gwelo Forest, Rhodesia; production began in 1906.
1906, August 1st. First Arkansas diamond found in Pike Co.
About 1906. Meerschaum found in New Mexico.
1907. First Congo diamond found; production began in 1913.
Benitoite discovered in So. Cal.
1908, April. Cape "boy" finds first South West African diamond.
Opal recognized at Lightning Ridge, Australia, by Charles Nettleton.
Opals found in Humboldt Co., Nevada.
1909. F. W. Martens, prospector, discovered Namaqualand diamonds; more important finds in 1925 led to commercial exploitation in 1926.
1909–10. Diamonds found in Liberia.
1910. Beryl and rose quartz found in South West Africa, near Rössing Station.
1912. True emeralds found at Bom Jesus dos Meiras, Bahia, Brazil, and in 1917 at Esmeraldas, Minas Geraes.
1912–13. Poonah Emerald district, West Australia, discovered, but production even on small scale only began in 1926.
1913. First diamond found in Tanganyika Territory; production began in 1925.
1915. Kashmir beryl localities discovered.
1915–16. Stuart's Ridge opal field, South Australia, discovered.
1919. February 4th, Sir Kitson finds first diamond on Gold Coast.
1919–20. Black opal district of Tintenbar, New South Wales, found.
1925. Prospectors find sapphires in eastern part of Belgian Congo.
1926. Lichtenburg increases South African alluvial production tremendously.
1927. Emeralds found in Leydsdorp district, Transvaal, South Africa.

CHRONOLOGY OF GEM MINING.

Table 3 presents a chronology of gem mining; and Figs. 1–3 show the geographical distribution of the known gem mines of the world at 1,000 B.C., 1 B.C., and 1500 A.D.[6] It is believed that

[6] For present day gem occurrence map, see this journal, vol. 17, p. 578, 1922.

the information on which these maps are constructed is sound, but some day more data will be at hand, particularly if some Mæcenas sees fit to furnish to the chemist and petrographer bits

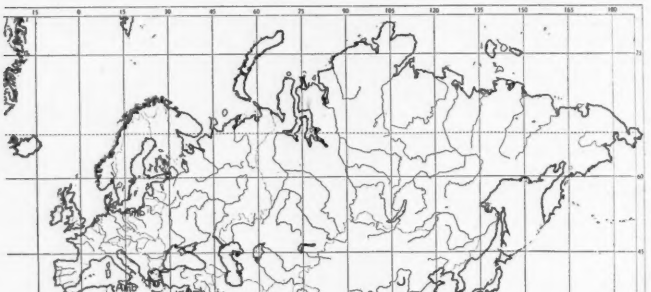


FIG. 1. Sources of gems known 1000 B.C.

of gems from ancient jewelry for comparison with stones from known sources.

DISCOVERERS OF GEM DEPOSITS.

The discovery of a gem deposit frequently requires two persons, the finder and the identifier of the gem. It is fitting here to record the name of the first individual to increase our reserves of gems whose identity is known to us, that of the Egyptian Captain, Haroëris, who about 2000 years B.C. led one of

Amenemhet II's expeditions to the Sinai peninsula for turquoise. So far as I know he was the first to qualify for membership in our Society. His early development work at Serabit was disappointing but with fine optimism he kept on, until he and his men were almost in despair for "the desert burned liked summer: the mountain was on fire." Finally, he questioned certain old miners who knew the pattern of the deposit, and they like old miners of today expressed their confidence in the mine, saying "There is turquoise for eternity in the mountain." That very day good ground was encountered and three months thereafter Haroëris, loaded down with turquoise, returned to Egypt.[7] Some 1500 years thereafter a party of pirates, shipwrecked upon an island in the Red Sea, were the next discoverers known to us. In their search for water in the rock crevices of Zebirget Island they found olivines, and indeed the paramount source of that gem.

That the professional gem hunter is coming into his own is indicated by the professions or trades of the 70 finders whose occupations are known to us. Of the 15 finders of gem deposits prior to 1800 A.D. but 4, or 27 per cent., were mining people (two prospectors, a mine captain and a naturalist), the other 11 including three soldiers, two missionaries, a farmer, a mountaineer, a trader, a hunter, a government official and a pirate. In the 19th century, of the 37 finders, twenty-one, or 57 per cent., were mining people (11 prospectors, 4 miners, 3 mineralogists, a geologist, an engineer and a jeweller), the others including two farmers of the peasant class, two slaves, two hunters, two groups of children, a traveller, a forester, a charcoal maker, an uneducated native, an explorer, a naval officer, a missionary and a band player. Of the 18 finders of gem deposits in this the 20th century, 16, or 89 per cent., were mining people (9 prospectors, 5 geologists and 2 mining engineers), and of the other two, one was a farmer and the other (the discoverer of the South West African diamond fields) a Cape "boy" who became familiar with diamonds while employed in the Kimberley Mine. Evidently gem discovery has

[7] J. H. Breasted: Records of the Past: Ancient Records of the Egyptians, vol. I., page 120. General historical sketch, S. H. Ball, Eng. and Min. Jour., vol. 123, pp. 483–5, 1927.

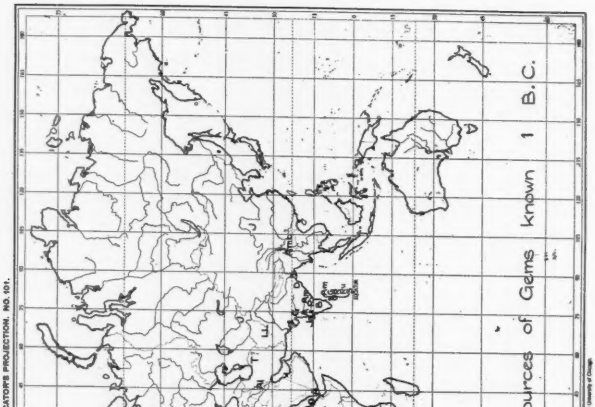


FIG. 2. Sources of gems known 1 B.C.

progressively become less a matter of chance and more a result of trained technique.

As a recent example of the application of scientific geology to gem finding, we need only refer to the development of the Namaqualand diamond fields through close physiographic studies of ocean terraces by Dr. H. Merensky and his assistant, Dr. E. Reuning.[8]

Before the beginning of the 19th century the identifier of gems was usually a jeweller or a diamond merchant: in the 19th century, however, 70 per cent. of the recorded identifiers were geologists or mineralogists and in the 20th century but 14 per cent. were jewellers, the others being mineralogists or geologists.

PRODUCTION.

Due to the present great wealth of the world and to the high technical attainments of mining, gem production has reached unprecedented heights. But at other prosperous periods of the world's history, the demand for luxuries speeded up gem production; this was true in the time of the Egyptian Empire, in the days of the Roman Empire and in the heyday of the prosperity of the Italian cities and of Spain. Indeed, the production of precious stones has always been a good business barometer.

Today the statistics of precious stone production are rather fragmentary, and such as exist are scattered through many tomes. Sixty years ago they were practically non-existent. The curve of production for the 18th and 19th centuries and the first 29 years of our century (Fig. 4) is schematic rather than accurate, although it is believed in a broad way to portray the remarkable growth of the industry and, one may add, gem consumption, for the two are for all practical purposes equivalent to one another. In the 18th century the production was stabilized at from $3,500,000 to $5,000,000 a year: it then rose gently to approximately $8,000,000 by 1871, after which with the increased exploitation of the South African diamond mines there was a precipitate rise to a peak production of $97,000,000 in 1928, with deep canyons

[8] Alex L. du Toit: ECON. GEOL., vol. 25, pages 653–7, 1930.

FIG. 3. Sources of gems known 1500 A.D.

representing the World's War and the 1921–1922 post-war depression. It will be noted that at present the annual production is about 22 times that at the beginning of the 17th century, is 9½ times that of 1850 and is 3.6 that of 1900. The world's daily diamond production is now more than that of a month at the beginning of the 18th century. Along the same lines, Dr. George F. Kunz[9] said that the White Cliffs opal district alone "has produced during the past ten years [1890–1899—S. H. B.] more opals, and as fine if not finer ones, than have the famous Royal Hungarian mines in the centuries of their production."

Rapid as has been the growth of the industry, its expansion is relatively small compared to the increase in the production of copper and gold. In comparison with the dollar production in 1800 the present production of copper is over 10,500 per cent.; of gold, about 3,500 per cent.; and of precious stones, 1,915 per cent.

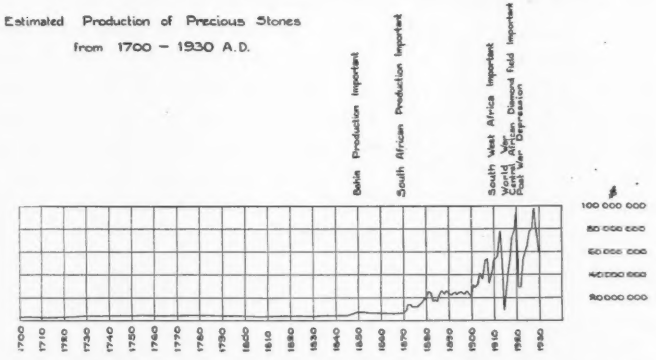


FIG. 4. Estimated production of precious stones from 1700–1930 A.D.

Incidentally, we may add that it was only in the last half of the 18th century that the value of the world's copper production passed that of precious stones, although now almost ten times it.

At the beginning of the 18th century diamonds accounted for about 50 per cent. of the yearly product but the popularity of that

[9] U. S. Geol. Surv. Min. Res., 1901, p. 760.

gem has so increased that it now represents about 95 per cent. of the total. In other words, the great increase in production has been due to an increase in diamond output.

The production from alluvial mines was on the whole largely predominant from about 100,000 B.C. to about 1878 A.D., although from 3500 B.C. to 600 B.C. there were probably years in which the turquoise from the Sinai mines (and probably lapis lazuli from the Afghanistan mines) was of greater value than the product of the alluvial mines. From 1878 to 1921 A.D., due to the large output of the pipe diamond mines of South Africa, underground production exceeded that of the gem placers. A series of remarkable alluvial diamond discoveries reversed the picture and in 1929 the alluvial mines accounted for 65 per cent. of the world's production and underground mines 35 per cent.

We have already stressed the age of the industry, nevertheless the output of relatively recent discoveries accounts largely for today's production. Of the 1929 production, 95 per cent. came from gem fields discovered since our own Civil War. While this is true, we need only cite the lapis lazuli mines of Afghanistan and the amber production of the Baltic Coast to show that some gem deposits are long-lived. Certain gem fields appear to have wonderful vitality, as instanced by the recent discovery of magnificent sapphires in the Ceylon gravels, which by now have been exploited for over 2,500 years. On the other hand certain fields appear to have been exhausted and in instances even the exact locality of the mines is lost. The sard locality near Babylon was even exhausted by Pliny's time.

From approximately 3500 B.C. to about 200 B.C., Egypt, drawing on its turquoise, emerald, olivine, and semi-precious stone mines, was the world's most important gem producer. India and Ceylon then replaced Egypt, and they in turn were only supplanted by Brazil in the third decade of the 18th century of our era. In the seventies of the last century, Brazil lost the premier position to South Africa, which so far as we can foresee is not likely soon to be replaced. How far India and Ceylon have fallen from their proud position as leaders in the industry 200 years ago is shown

by the fact that they, including Burma, now account for less than one per cent. of the world's production.

Gem production at first was undoubtedly by the individual prospector but in the fourth millennium before Christ we find the pharaohs dispatching large expeditions to the Sinai peninsula to mine turquoise at governmental expense. The Assyrian kings also financed lapis lazuli mining. In the Middle Ages, the majority of the great gem fields of the world were royal monopolies, farmed out to *entrepreneurs* on a royalty basis (the Indian diamond mines, Burmese ruby mines, Prussian amber mines) while the mines of the Inca Empire, were state enterprises. In many cases, stones of unusual size became theoretically the property of the potentate. I say theoretically for frequently the large stones were at once broken into smaller fragments. Company operating of gem mines is a relatively recent development, the oldest company known to me being the Granaten Gewerkschaft, which was formed in 1715–1716 to exploit Bohemian garnet placer deposits.[10] At the present time the large diamond mining companies dominate production, nine of them accounting for 52 per cent. of the world's gem production.

Large as the present production is, I think we may confidently expect a further increase, for greater world wealth facilitates its desire for gem adornment, and the dollar total will be increased in part by mounting per carat prices of the ruby, sapphire, and emerald. A corollary of this increase will be continuing increased percentage of the whole production assignable to the diamond.

Undiscovered Gem Resources and Production Possibilities.—Past experience has proved that guesses as to the ability of the world to produce minerals from deposits as yet unknown are dangerous. A guess however may be of some value. Weighing the potentialities of each country and the degree to which each has been prospected, it is my impression that about one-half of the world's gem deposits have been found. Due to the dominant position of the South and Central African diamond mines in the industry, however, I do not expect the total productive possibilities

[10] Dr. G. F. Kunz: Trans. A. I. M. E., vol. 21, pp. 241–50.

of the deposits still to be found to approach those now known. At no time in the history of the art have we had such a reserve of gems blocked out ahead of mining. Fields are exhausted, to be sure, but new discoveries replace them. My impression is, however, that with the continually mounting demand the future is by no means assured, more particularly as to rubies and to a less extent as to sapphires and emeralds and in a decade or two as to diamonds.

So far as we can now foresee, gem prospecting will receive no such impetus as will the search for sulphide ore bodies through the use of geophysical methods of prospecting. Several of the methods now applied could be used in locating pipes of kimberlite, but kimberlite does not necessarily contain diamonds and long and expensive tests would have to be carried on at 50 or 100 pipes before a commercial one might be located. Electrical or magnetic methods might also be used in exceptional cases to trace out alluvial deposits where the gems are in association with much magnetite or ilmenite. This new tool on the whole, however, appears of little value to the gem prospector. Nor are the laws of supply likely to be upset by new milling processes, as were those of zinc and silver through by-product production as a result of the application of the flotation process. There are few cases of by-product production in gem mining. It is true that sapphire and spinel in addition to ruby are recovered in the Burmese ruby mines, that pyrope garnet is an insignificant by-product of the pipe diamond mines of South Africa, and that several precious stones occur together in some of the gem gravels, but such by-product production is on the whole unimportant.

As the chronological table shows, the discoveries have been more frequent with advancing time. This is only in part due to the fuller data available as to recent gem discoveries. The potentialities of the gem discoveries of the last sixty years greatly exceed those of all preceding time. The table indicates that for the past 80 years the discoveries have been stabilized at about eight per decade notwithstanding the fact that for the last twenty years the number of seekers after gems is greater and their skill greater than in the previous sixty years. This indicates that the easily

found deposits have been discovered and suggests that over half of the world's deposits have been found. Of course, the future will, however, see many important gem discoveries.

The geographical loci of gem discoveries of more or less importance through the centuries have varied in percentages as follows:

Time.	Europe.	Asia.	Africa.	N. America.	S. America.	Australia.
Prior to 1 A.D.....	19	52½	28½	—	—	—
1–1,500 A.D.....	30	35	5	25	5	—
1,501–1,800 A.D.....	32	21	3	12	29	3
1,801–1,900 A.D.....	13	24	8	30	14	11
1901 to date.....	—	4	52	20	4	20

The decreasing relative importance of Asia and Europe as fields of new discoveries and the recrudescence of African discoveries under prospecting by white men is particularly interesting.

HISTORY OF THE GEM FIELDS.

Below is a summary of present day knowledge of the history of the more important gem fields of the world:

Diamonds.—India is incontestably the oldest diamond field in the world, and as a source she was predominant until the third decade of the 18th century when Brazil took the lead. It has been the custom to consider the exploitation of the Indian fields ancient, and by many authors the discovery is dated several millennia before Christ's birth. I feel that this is an error although admittedly the evidence is inconclusive. The great age attributed by some to Indian diamond mining appears to be based largely on statements of the Mahabharata and other Hindoo books. In their present form however these books only date from about 200 A.D. and to base history upon these legends is at least unscientific. Hindoo archæology offers us no aid, for so far as I know diamonds do not occur in any ancient Hindoo jewelry, and if we disregard the old Hindoo legends we must look beyond India for evidence as to when her diamond fields were discovered.

Disregarding the extraordinary discoveries of Sir John Marshall in Punjab, suggesting a connection between a people of that

region and the Sumerians early in the third millennium B.C., India on the one hand, and the Mesopotamian countries and Europe on the other, have been in commercial intercourse practically continuously since about 900 B.C. From about 900 B.C. to 562 B.C. the Assyrians imported from India teak wood and many other products, and thereafter the Persians, the Greeks and the Romans consecutively had commercial intercourse with India. It is noteworthy that Ktesias (416–398 B.C.) states that Assyria obtained from India material for her finer seals, and in support of his assertion it may be mentioned that sard and sardonyx first appear in the Mesopotamian valley in Assyrian times. The source of these and also of topaz, which appears contemporaneously may well have been India. While she had emeralds, probably from Egypt, she had neither the diamond, the ruby, or the sapphire. The Greeks and the Romans, on the other hand, had all of these. The proponents of a very ancient discovery of the Indian diamond may hold that the then reigning Indian monarchs did not permit the export of diamonds to Assyria; but in the Middle Ages when the Hindoo monarchs owned the mines and when they took as their right all sizable stones, they permitted the export of the smaller stones. Further, had diamonds in Assyrian times existed in the hands of the Hindoos, it is reasonable to suppose that some merchant less law-abiding and more daring than the ordinary, would have, for gain, smuggled diamonds from India.

The earliest instance of the use of diamonds by the Greeks or Romans is a very beautiful bronze statuette of Greek origin in the British Museum. "Minute natural crystals of diamonds are fixed in the pupils of the eyes, giving a wonderful look of life and spirit."[11] This is Bronze No. 192, which H. B. Walters[12] believes to date from 480 B.C., Middleton also dating it in the latter part of the 5th century. Other Indian products used by the Greeks about the same time (*i.e.*, 460 B.C.), were rice and peacocks.[13] A number of Roman rings set with uncut diamonds

[11] J. Henry Middleton: The Engraved Gems of Classical Times, etc., p. 130, Cambridge.

[12] Catalogue of the Bronzes, British Museum, London, 1899, p. 17.

[13] A. A. MacDonell: India's Past.

exist in museums but these are of relatively late age, most of them certainly after the time of Christ. It should, however, be remembered that the diamond is a rare substance and it is possible that at some future date the archæologists will make discoveries of still earlier use of the gem.

Some believe that the use in gem engraving of the "diamond" point, a drill mounted with a fragment of some hard substance, shows that diamonds have long been known. The "diamond" point was used by lapidaries even in Etruscan times, but considering the hardness of the stones engraved in classical times, a fragment of emery or corundum would serve as well as one of diamond.

It is frequently stated that the Indian paragons, or large diamonds, have histories dating back millennia. We know however that most of the large diamonds were found relatively recently, the Regent, for example, in 1701. The single possible exception is the Koh-i-nur, which had been in the family of the Rajah of Malwa a long time previous to his defeat by the Sultan Ala-ed Din in 1304. An owner is named in 57 B.C. but his existence is doubtful.[14] In short, the history of the Koh-i-nur dates back some 900 years; earlier than that we must depend on legend and not on history.

The earlier Greek authors do not describe the diamond. There is no reference to the diamond in Ktesias' description of India (416–398 B.C.); Theophrastus mentions an "adamas" uninjured by fire, but I am inclined to believe this magnetite.[15] Nor does the well-informed Strabo (B.C. 54–A.D. 21) mention diamonds as among India's precious stones. Manlius, a Roman poet and astronomer, wrote in 16 A.D. in the 4th book of his poem, Astronomicum, "Sic adamas, punctum lapidis, pretiosior auro" ("A particle of stone more precious than gold"). The reference may indeed be to the diamond, and yet to say the least the description is vague. Pliny's description of it (77 A.D.) as a gem so valuable that it was "only known to kings" and his comparison of the

[14] Edwin W. Streeter: The Great Diamonds of the World, pp. 117–19, London, 1882.

[15] Mineralogy of Theophrastus, Chap. 32 (371–266 B.C.), Hill translation, p. 47

form of the Indian variety to that of "two whip-tops placed base to base" is exact enough to satisfy the most captious. The identity of his other varieties is doubtful and most of them were certainly not diamonds. Athenaeus of Naucrates, Egypt, states that the Pharaoh, Ptolemy Philadelpheus (309–246 B.C) had diamonds, not in itself improbable, as this king went far afield for the luxuries of his court; but as Athenaeus post-dates the king some 500 years his evidence is not weighty. Juvenal who lived from 60–140 A.D. mentions[16] in a ring an "Adamas notissimus" which Agrippe (63–12 B.C.) placed on the finger of his sister-wife. Mark Antony, in 33 B.C., is supposed to have had diamond buttons on the purple robe which he wore at the coronation of Cleopatra and her children.

The "Periplus of the Erythraean Sea" (written in the first century A.D.) records the exportation of diamonds from the ports of Bacare and Nelcynda, India.[17] Ptolemy (an Alexandrian who lived about 150 A.D.) refers to a diamond-producing river in India.

According to B. Laufer,[18] Indian diamonds were mentioned in the annals of the Táng Dynasty, 221 A.D. According to him the Hindoo Purānas, in which diamonds are divided into castes, while they may date from the first centuries A.D., are probably much later. He calls attention to an article by S. K. Aiyangor[19] in which it is stated that the first Hindoo reference to the diamond is made in the Artha Sastra of Kautilya, probably written at the commencement of the 3d century B.C. Therein six kinds of diamonds, according to the mines from which they come, are described. In the questions of King Milinda, written in the beginning of our era, the diamond is mentioned.

Of the European middle age travelers Marco Polo (1271–1295 A.D.) is the first to mention India's diamonds, followed by Friar Jordanus.[20] The friar, who travelled about 1330 A.D., says India

[16] Nat. History, Book VI., p. 156.

[17] Wilfred H. Schoff, Transl.: p. 45, New York, 1912.

[18] The Diamond: A Study in Chinese and Hellenistic Folk-lore, pp. 16, 44–5. Chicago, 1915.

[19] Quart. Jour. Mythic Society, vol. III., p. 129, Madras, 1914.

[20] The Wonders of the East, Hakluyt Society, p. 20.

"has the best diamonds under heaven." Thereafter practically every traveler mentions them.

From Tavernier and other travelers we learn that most of the fields worked in the 17th century were at that time relatively recent discoveries; the Kollur district, for instance, is said to have been discovered by a poor farmer who in planting millet in 1560 found a 25-carat stone. Upon its definite determination as a diamond by a Golconda diamond merchant, the 16th century version of a "rush" was on. The Sambalpur district is one of the oldest known and may be the locality mentioned by Ptolemy. India as a diamond producer reigned supreme until supplanted by Brazil; the known deposits are now, however, pretty well exhausted and she now accounts for only 1/700 of 1 per cent. of the world's production.

In resumé, the earliest diamond known probably reached Europe about 480 B.C.; the earliest Hindoo reference to it post-dates 300 B.C.; it was not mentioned by classical writers before the beginning of our era; and was not an article of commerce when Assyria and India were in close commercial contact about 900 B.C. While an occasional stone may have been picked up previously, I am strongly of the opinion that the industry dates only from about 800 to 600 B.C. and that for some centuries thereafter the production was small. By about 600 A.D. it was important, reaching its zenith perhaps in the 17th century.

Perhaps reference may be made here to the peninsula of India, which in classical times held a position as a source of precious stones almost unbelievable in view of its present meager production. It is believed that diamonds were found there some time between 600 and 800 B.C.; its agates appreciably before 400 B.C.; its beryls at least in the 4th century B.C. and probably much earlier; and its garnets well before the time of Christ.

Megasthenes (302–288 B.C.) states that the clothes of the Hindoos "were decorated with precious stones." Strabo[21] (circum B.C. 54–A.D. 21), tells of a trip made to India by Eudoxus of Cyzicus about 120 B.C. He returned to Egypt with precious stones "some of which the Indians collect from amongst the

[21] Strabo: Geography, vol. I., p. 149.

pebbles of the rivers, others they dig out of the earth, where they have been formed by the moisture as crystals are formed with us." Writing in the 1st century B.C., S'udraka in his play "The Toy Cart" describes a jeweller's shop "where skillful artists were examining pearls, topazes, sapphires, emeralds, rubies, lapis lazuli, coral and other jewels; some set rubies in gold, some work gold ornaments on colored thread, some string pearls, some grind the lapis lazuli, some pierce shells and some cut coral." [22] The Indian laws, dating in their present form slightly before the time of Christ, especially admonish the trading class, the Vaisyas, to study the prices of precious stones so they can trade intelligently.[23] In Pliny's time the precious stone industry must have been an old one, for he reports that the Indian lapidaries were already remarkably skillful in imitating precious stones, particularly beryl,[24] and it is probable that the art could only have arisen long after the gems were known and in demand. Pliny, after informing us that in his time all opals came from India, adds: "thus completing her glory as being the great producer of the most costly gems." Elsewhere [25] he adds: "of all countries India is the most prolific of them [precious stones]." In the Stûpa at Bhattiprôlu, of the time of the Andhra dynasty [26] (220 B.C.–236 A.D.), ornaments of beryl, amethyst, rock crystal, yellow quartz and garnets were found. At another nearby, amber beads were also recovered. Ambassadors from India to Augustus (about 20 B.C.) came "with jewels and pearls." [27]

In the "Periplus of the Erythraean Sea," [28] probably written by an Egyptianized Greek of the first century of our era, "transparent stones of all kinds, diamonds and sapphires" are listed as exports of the Indian seaports Bacare and Nelcynda.

C. W. King [29] gives the following poem written by Dionysius Periegetes, a poet who probably lived about 100 A.D.:

22 Wilson: Hindu Theatre, vol. II., p. 85.

23 Manu, IX., 329.

24 Natural History, Bohn Library Edition, vol. VI., p. 415.

25 *Op. cit.*, p. 464.

26 Arch. Surv. of India, vol. XV., p. 51, Alex. Rea, Madras, 1894.

27 Q. Curtius Rufus, Invasion of India by Alexander the Great, Book IV., Chapter 12. J. W. McCrindle, Trans., Westminster, 1893.

28 Wilfred H. Schoff, *op. cit.*, p. 45.

29 Antique Gems, p. 3, London, 1860.

Some [Indians] seek amidst the pebbles of the stream
The verdant beryl, or the diamond's gleam,
Or where the bright green jasper meets their view,
Or the clear topaz shows its lighter hue,
Or the sweet amethyst which serenely bright,
Diffuses far and wide its tranquil light.
The land thus blessed with rivers never dry
To all her sons doth constant wealth supply.

To this day the application of "Oriental" to the finest colored gems is a heritage of India's ancient richness in precious stones.

The other eastern diamond source, although one of secondary importance, is Borneo. The first definite reference to it is that of Pedro Teixeira,[30] a Portuguese physician who spent the years from 1586–1601 in India and returned there in 1603. I am inclined to ascribe the discovery to Hindoo emigrants, the first of whom arrived in the diamondiferous southwest part of the island in the first six centuries of our era, for neither the aborigines nor the Chinese who reached the northern non-productive part of the island about the same time were acquainted with diamond mining. We may tentatively place the discovery from the 6th to 10th century of our era.

The next discovery was that of the Brazilian mines, one of the world's major fields. The discovery was probably made in Minas Geraes about 1720, although only officially announced in 1727, the year in which export began.[31]

The story of the discovery of the world's premier diamond field, South Africa, is well known. In 1867, John O'Reilly, a trader, was intrigued by a pebble which a farmer's children had found and with which they were playing. It was given to him. He finally sent the stone to Dr. William Guybon Atherstone, a mineralogist, who identified it as a diamond and with great vision saw the commercial possibilities of the discovery. In March, 1869, the Star of South Africa was found and, as a result of the publicity given the discovery of this fine gem, confidence was created in the field, which to the end of 1928 had produced diamonds worth some $1,376,000,000. While by no means as well

[30] Hakluyt Society, 1902, p. 232.

[31] S. H. Ball: Mining and Met., vol. 12, pp. 282–5, 1929.

known as the Koh-i-nur, the Star of South Africa, which caused the development of these fields, is the most important diamond ever found. Commercial production began early in 1870 at Pneils. De Klerk, a farm overseer, digging in a dry water course because of the presence therein of garnets and rounded agates, located the first of the pipe mines, Jagersfontein, in August, 1870. The Kimberley pipes were found later in the same year and the diamond industry, the originator of South Africa's prosperity, was established. The Premier mine began production in 1903. the discovery having been made in the previous year by T. M. Cullinan. Diamonds were found in Namaqualand in 1909 by a German prospector, F. W. Martens, but the first commercial discoveries were made in 1925 and production began in the following year. The discovery of the Lichtenburg alluvials in 1926 increased the South African production tremendously for two years.

The first stone in the British Guiana deposits, a field of secondary importance, was found in 1888 by Edward Gilkes, an intelligent colored gold prospector. He suspected the nature of the stone and submitted it through his partner, R. T. Kaufman, to the late Sir John B. Harrison, colonial geologist, who determined it. Production began in 1890.

The discovery of the first stone, a desert pebble, in the important South-West African diamond fields, was made in April, 1908, by a Cape "boy," an ex-employee of DeBeers, where he had become familiar with diamonds. The first stone in the important Congo-Angola diamond field was found in 1907 but due to the hostility of the natives production only began in 1913. In February, 1919, Sir A. E. Kitson, head of the Colonial Geological Survey, found diamonds on the Birrim River, Gold Coast.

Ruby.—The Greeks and Romans presumably obtained rubies from Ceylon and to a less extent from India, where a few are found. The major present source of supply is Burma, with minor contributions from Siam, Ceylon, and Badakhshan. There are in the Shan records many early references [32] to mines of questionable value, and one avers that in the 6th century the

[32] N. M. Penzer: The Mineral Resources of Burma, p. 25.

Shan kings received about 7 pounds of rubies annually from a Shan princeling living in the general vicinity of Burma. Marco Polo, however, who travelled from 1271–1295 A.D., did not know of the Burman source, and states [33] that Ceylon "produces more beautiful and valuable rubies than are found in any other part of the world."

Hieronimo de Santo Stefano, a Genoese merchant who visited India in the latter part of the 15th century, writes that 15 days' journey from Pegu is Ava, "in which grow rubies and many other precious stones." [34] Duarte Barbarosa,[35] who travelled from 1501–1516 in the East, states that the Burmese rubies surpass the Ceylonese and that rubies and spinels are found in Burma "in the mountains on the surface of the ground." This seems to be a definite reference to the Mogok deposits. He mentions them as a standard article of trade in the gem bazaar of Vijayangar, India, and contemporaneously they were exported to Europe from Calicut. Ludovico Varthema, 1503–1508, also mentions Burmese rubies. Caesar Frederick (1563–1581) bought rubies in Burma and sold them in Ceylon,[36] and he reports that the king of Pegu was already known as "Lord of the Mines of Rubies, Safires and Spinels." I think it is probable that the mines were found in the 14th, although possibly some centuries earlier. In 1597, a Burmese king with rare financial acumen obtained the ruby-producing towns of Mogok and Kyatpyin from the Shan ruler in exchange for Tapoung, an unimportant town on the Irrawaddy River.[37] Tavernier describes the mines and states that Burma's yearly production in the middle of the 17th century was worth £22,500. The first European in modern times to visit the mines was Pére Guiseppe d'Amato, in 1883. The Burma Ruby Mines Ltd. was formed in 1889, and operated with indifferent success until 1925, when it was decided to liquidate the company. The finding of many fine sapphires in the

[33] Travels of Marco Polo, p. 349.
[34] Hakluyt Society: India in the 15th Century, vol. III., p. 6.
[35] Hakluyt Society: Series II., vol. 46, p. 154, 1918.
[36] Hakluyt Voyages, vol. V., p. 443.
[37] Ralph Stokes: Mines and Minerals of the British Empire, p. 27, London, 1908.

Kyaungdwin mine in April, 1926, however, may rejuvenate Burmese gem mining.

Sapphire.—Ceylon and, to a much less extent, India were presumably the source of the Greek and Roman sapphires. Sapphires first appeared in Western jewelry among the Etruscans (600–275 B.C.), and were used by the Greeks and Romans from 480 B.C. on. Dr. C. W. King[38] describes a sapphire cameo of Hadrian's time (A.D. 117–138) with a hole drilled through it. It must, originally, have been a part of a Singhalese or an Indian necklace or earring. Ceylon very early produced gems, for the Mahawanso,[39] a Singhalese chronicle written in the 5th century of our era, states that the king of the Nagas, an aboriginal tribe, had a "throne of gems" before the Aryan chieftain, Vijaya, conquered the island (B.C. 543). Feeble support to the earliness of the discoveries is found in the Chinese chronicles, for one states that when Buddha (624–544 B.C.) visited the island, he sprinkled "the land with sweet dew which caused it to produce red gems,"[40] and in consequence it became the resort of traders. Fa-Hien, the Chinese Buddhist traveler of the 5th century, claims Ceylon was visited by gem traders before Buddha's time.[41] With the advance in civilization consequent to the arrival of Vijaya and his vassals (B.C. 543), exploitation doubtless expanded. Devenipiatissa, in 306 B.C., sent ambassadors to Asoka, the powerful Indian king, their presents including pearls, sapphires, rubies and lapis lazuli, the latter of course an import into Ceylon, itself.[42] Pliny (77 A.D.) states that in the time of Emperor Claudius (41–54 A.D.) ambassadors of the Island of Taprobane boasted of the fine precious stones it produced. As Megasthenes (302–288 B.C.) mentions its pearls but not its precious stones, their fame at that time was not as yet general.[43] Precious stones, however, may possibly have been known in Megasthenes' time, as his work has only come down to us in fragments. Ptolemy (circum 150

[38] Antique Gems, p. 50, London, 1860.
[39] J. E. Tennent: Ceylon, vol. I., p. 331, London, 1860.
[40] *Op. cit.*, p. 613.
[41] *Op. cit.*, p. 335.
[42] *Op. cit.*, p. 446, in which Tennent quotes the Mahawanso.
[43] Nat. History, Book VI., chap. 24.

A.D.) specifies "hyacinth" (sapphire) as among the products of Ceylon.[44] The Periplus (dating from the 1st century of our era) mentions among the exports of Ceylon "transparent stones" and sapphires from the Indian ports of Bacare and Nelcynda. Solenus (3d century A.D.) and Cosmos, a monk who lived about 545 A.D., both report the occurrence of sapphire in Ceylon, the former adding that they were obtained from gravels. Abu Zeid al Hosan, an Arabian traveler of about 850 A.D., mentions that its precious stones are found both in stream gravels and in solid rock. Marco Polo's statement[45] follows:—"The island produces more beautiful and valuable rubies than are found in any other part of the world, and likewise sapphires, topazes, amethysts, garnets, and many other precious and costly stones." Oderic (1318 A.D.) and Friar Jordanus (1330 A.D.) are the next to mention its wealth in precious stones.

That even in a gemmiferous region exploited for some 2500 years discoveries of importance are possible is proved by the finding of remarkably large and fine sapphires at Pelmadulla, 50 miles from Colombo, in 1924. It may be remarked that the name of the principal city of the gem-bearing region, Ratnapoora, means "City of Rubies" and that the historian Al Baladhuri of Bagdad, who died 892 A.D., called Ceylon "The Isle of Rubies." The Chinese as early as the 6th century, in translating the Sanskrit Ratna-dwipa, called Ceylon "Paou-choo" or the "Isle of Gems."

In Manual de Faria's (1617 to 1640 A.D.) description of Portuguese Asia[46] it is stated that Siam has "mines of sapphires and rubies." It is possible that this was at that time a recent discovery, for in the "Account of Java" written in 1603–1605[47] Siam is said to import from Pegu many "rich precious stones." Sapphires are found over an area of several hundred square miles east of Chantabun on the gulf of Siam. The earliest specific reference I find to the precious stones at Chantabun is Crawfurd's statement (1828) that rubies occur there.

[44] Hakluyt Society; No. 98, p. 364, J. W. McCrindle, transl.
[45] *Op. cit.*, p. 349.
[46] Kerr's Travels, vol. VII., p. 36.
[47] *Idem*, vol. VII.

The occurrence of rubies and sapphires southwest of Battambong, Cambodia, has been known for generations.[48] Tavernier, who traveled from 1631 to 1668, may refer to them when he mentions the occurrence of rubies in the mountains which run from Pegu towards the kingdom of "Camboya," but the mines have been regularly worked only since 1875. Sapphires also occur at Phailin in Cambodia, about 50 miles southwest of Battambong. Blue stones in the possession of the natives, the character of which was unknown to them, were recognized as sapphires by Burmese travelers about 1885. Mining began immediately after the recognition.

The sapphires of the Zanskar district, Kashmir, were an important factor in the market from 1882 to about 1905, when the deposit was practically exhausted.[49] Several stories exist as to the discovery, the one generally accepted being that a hunter lost his gun flint and the substitute which he picked up happened to be a sapphire. Naturally enough it served more than satisfactorily, and after he had carried it a long time, it attracted the attention of a Laholi trader, who early in 1882 took it to Simla, where Mr. F. R. Mallet identified it. The place was then found and Laholis sold many at Simla at a low price. That the stones had been only recently exposed by a landslide when first discovered seems well established.

About 1865 the Montana gold miners noticed in the riffles of their sluice boxes transparent pebbles of attractive color. They were soon identified as sapphire but were disregarded, as the miners' interest was centered on gold. In 1889 the first stone was found in a dike. In 1893 European experts reported favorably on the field but the first companies, being over-capitalized, soon failed. In cleaning up the sluice-boxes of an unsuccessful gold placer on Yogo Creek in 1895, sapphires were found and were identified in November of that year. In February, 1896, John Ettien, a prospector, found sapphires on the uplands nearby in the weathered outcrop of a dike. This led to successful lode mining.[50]

[48] Campbell: Siam in the 20th Century.
[49] T. H. D. La Touche: Geol. Surv. India, vol. XXIII., p. 59, 1890.
[50] W. H. Weed: 20th Ann. Rept. U. S. Geol. Survey, Pt. III., pp. 454–9.

John Evans, a gold prospector, found a sapphire in the Anakie district, Queensland, in April, 1876. Mining was not, however, commenced until 1881 and then in a desultory way until 1891, when the scale of operations increased.[51]

Emerald.—The earliest known emerald mines of the world are those of Jebel Sikait and Jebel Zebara on the Egyptian coast of the Red Sea. The earliest tools which can be definitely identified date from the time of Sesortosis II. of the XIIth dynasty (about 1925 B.C.) These mines have been intermittently worked since then.[52] Dr. Max Bauer[53] states that the Salzburg Alps emerald mines have been worked since the time of the Romans. Neither of these sources are now of importance.

The Colombian emerald mines had been worked by Indians an unknown but long time before the Spanish conquered the country, the Chibchas working the Coscuez and Chivor-Somondoco mines, and the Muzos, the Muzo mine.[54] At the time of the arrival of the Spanish, emeralds were in the hands of the natives of Peru, Ecuador and Colombia in quantity, and according to Gregory Mason were in the possession of the Mayas by the 10th century, suggesting that the Colombian mines were opened at that date. This was about the time when the Mayas imported from Costa Rica and Colombia the technique of metal working.[55] The very considerable number of emeralds in the hands of the Indians when the Spaniards arrived, together with their frequency in old Indian graves in Peru and Colombia, supports the thesis of a considerable age for the mines. Further, Montesinos, a priest resident in America from 1628–1642,[56] states that emeralds were among the spoils of the Inca Sinchi Roca when he entered Cuzco in triumph after defeating the Chancas Indians. This Inca lived about

51 B. Dunstan: Queensland Geol. Survey, Pub. No. 172, p. 20, 1902.

53 Precious Stones, page 316.

52 For details see Sydney H. Ball: The Jewelers' Circular, vol. 96, pp. 38–9, 1928.

54 J. E. Pogue: Trans. A. I. M. E., vol. 55, pp. 910–34, 1916; Pamphlet of Colombia Emerald Syndicate; Bauer: Precious Stones; Charles Olden: Trans. Inst. Min. & Met., vol. XXI., pp. 193–209; Benzoni: History of the New World; Hakluyt Society, 1857, pp. 109–12, etc.

55 Enc. Brit., New Vol. 1926, article on "Archaeology."

56 Fernando Montesinos: Memorias Antiquas Historiales del Peru, Hakluyt Society, p. 94, 1920.

1100 A.D. Wm. Bollaert[57] also reports that the ruler or Scyris of Caras, who conquered Quito about 1000 A.D., wore a large emerald, the hereditary emblem of his sovereignty, while the priests of coastal Peru aver that emeralds were part of the tribute of a great chief, Chimo Capac, of the early Chimu period (say 100 B.C.–600 A.D.).[58] That emeralds were carried as far north as Mexico seems doubtful.

The Spaniards should have been able for a time to satiate their desire for the gems by appropriating the stones owned by the Indians, but almost as soon as they arrived the mines were sought. It was first believed that the mines were in either Peru or Ecuador and the stones were known in Europe from the 16th century on as "Peruvian" emeralds and less commonly as "Spanish" emeralds. So obsessed were the people of the 16th and 17th centuries with the preponderant position of the South American mines that the great gem expert of the 17th century, Tavernier, knew of no source except "Peru" and he postulated a pre-Colombian trade in them to India and Europe via the Philippines. That the quantity obtained in South America was great is shown by the statement of Father Joseph de Acosta that two chests of emeralds, each weighing at least 100 pounds, were on the ship upon which he returned to Europe in 1587. Naturally, the price of the stones was adversely affected. Failing to find emerald mines in Peru, a party of Spaniards under Gonzalo Jiminez de Quesada pushed northward into present day Colombia, and on March 3d, 1537, a Chibcha youth offered the Spaniards at the village of Guacheta a gift of emeralds, and the next year an Indian showed one of Quesada's lieutenants, Pedro Fernandez Valenzuela, the Somondoco mine. This mine was worked till 1672, when it was abandoned, but was rediscovered by the correct interpretation of an old Spanish parchment map by Francisco Restrepo, a Colombian engineer, in 1896. The Muzo Indians could be induced by no means, fair or foul, to disclose the location of their mine, and in 1555 Luiz Lancheros founded in the region the

[57] Antiquarian, Ethnological and other researches in New Granada, etc., p. 84, London, 1861.

[58] P. A. Means: Ancient Civilization of the Andes, p. 64.

village of Santissima Trinidad de los Muzos. By 1558 the Cosquez mine had been located but hostile Indians forced the Spanish to abandon it. The important Muzo mine was only relocated by Captain Juan Penagos in 1594. It has since then been the chief source of the world's emeralds, although for short periods in the intervening 335 years the mine has been idle. As to the details of the discovery there is a legend that a Spaniard on reaching Trinidad one day noted that his horse limped; cause, an emerald imbedded in the animal's hoof, and by back-tracking he and the excited villagers found the Muzo mine.

The most important emerald mines of the Eurasian continent are those of the Takovaya district, Urals. In 1830 a peasant charcoal burner noted among the roots of a storm-uprooted tree an attractive, transparent, green mineral. This he took to one Kokovin, then manager of the imperial lapidary works at Ekaterinburg, who properly determined it emerald. Mining began at once and has with a few stoppages continued to the present day. Phenacite, beryl, and chrysoberyl are also mined.

Emeralds had been found in gravels at Emmaville, New South Wales, for some time but were first recognized by D. A. Porter, who found them in place in 1890. Mining, which began at once, has not been profitable.[59] The Poonah district, West Australia, was discovered late in 1912 or early in 1913 by a prospector, "Paddy" Ryan, but production even in a small way only began in 1926.[60]

The Brazilian "emerald," known to the trade for over three centuries, is a tourmaline, but true emeralds, of light color to be sure, were found at Bom Jesus dos Meiras, Bahia, in 1912 and at Esmeraldas, Minas Geraes, about 1917. Emeralds were found in the Leydsdorp district, northern Transvaal, late in 1927.

Beryl.—Beryl was known to the Egyptians over 5300 years ago, and to the Cretans about 4000 years ago. Beryl is associated with emerald in the Jebel Zebara mines (see Emerald). The fine beryls known to the early Greeks and Romans presumably came

[59] Edward F. Pittman: The Mineral Resources of New South Wales, Geol. Surv. of N. S. W., 1901.

[60] Mining Jour., London, vol. 100, p. 303, March 29, 1913.

from India, and the word beryl according to lexicographers is derived from the Sanskrit "Vaidūrya," a word probably of Dravidian origin. It may have been the first of the Indian gems known. The principal Indian source was the Coimbatore district. Strabo mentions its use in ornamenting the drinking cups of the Indians (B.C. 54 to 21 A.D.) and Pliny also gives India as practically the sole source in his time. Indeed, according to Q. C. Rufus,[61] the sceptre of Sopeithes, the native king resident at the modern Lahore, which, in recognition of his defeat, he gave to Alexander the Great, was of gold set with beryls. Ptolemy (about 150 A.D.) mentions the occurrence of beryls in southern India.

John Mawe states that aquamarines were exported from Rio de Janeiro in the first decade of the 19th century and the actual discovery doubtless appreciably predates that period. The beryl of the Mursinka district, Ural Mountains, was discovered in 1668 and the Siberian Altai Mountain localities were first mined at the end of the 17th century. Morganite, the beautiful pink beryl, was first produced from a pegmatite dike at Maharitra, Madagascar, in 1902,[62] but aquamarine had been produced in Madagascar prior to that date.

Spinel Ruby.—At present the spinel and balas rubies come from the Burma ruby mines, the Siam sapphire mines, and the Ceylon gem gravels. Badakhshan (Afghanistan), the most famous locality, is said to be approaching exhaustion. The Badakhshan locality is at least a thousand years old, for it was known to Istakhri (951 A.D.), Ibn Haukal (978 A.D.),[63] and Al-Ta'Alibi (961–1038 A.D.), Arab geographers. Mohammed Ben Mansur, writing in the 12th century, states that a hill at Chatlan in the time of the Abbasides, caliphs who ruled from 750 to 1258 A.D., was broken open by an earthquake and in the fracture in a white stone was found the "Laal-Bedaschan" (balas ruby). Women of the neighborhood tried to extract dye from the red stones, and failing threw them away. Later a jeweller saw them and recog-

[61] *Op. cit.*, Bk. 9, Chap. I., p. 220.

[62] L. De Launay: Gites Mineraux et Metalliferes, vol. I., p. 832, Paris, 1913.

[63] Translation by Sir Wm. Ouseley, p. 225, London, 1800.

nized their value. Marco Polo visited the mines in the last quarter of the 13th century. In his time both the mining and marketing were controlled by the king and the supply was strictly proportioned to the demand. A few true rubies are by-products of the mining. The Badakhshan spinel mines were presumably found sometime between 750 and 950 A.D.

Spodumene.—The earliest known gem spodumene, and this means the first transparent unaltered phase, was the yellow from Minas Geraes, Brazil, found about 1870.[64] It soon thereafter appeared on the gem market.[65] Hiddenite, the green variety, was first found about 1877, as residual fragments in the soil of North Carolina, by the children of a farmer living near Salem Church. The father brought samples to J. Adlai D. Stephenson, of Statesville, N. C., who in turn showed them to W. E. Hidden. The latter eventually found the gems in place in July or August, 1880, at Hiddenite (formerly Stony Point), N. C. For a time it was supposed to be diopside, but when in 1881 Mr. Hidden submitted specimens to Prof. J. Lawrence Smith, the true nature of the gem was recognized.[66] The lilac colored spodumene, so fittingly named kunzite after our learned friend, Dr. George F. Kunz, was discovered at the White Queen Mine, Pala, San Diego Co. California, early in 1902, by Frederick M. Sickler.[67]

Tourmaline.—It is probable that among the gems sent to Greece and Rome from Ceylon were tourmalines, but the supposition cannot be proved as no classical instance of the use of the gem is recorded. Indeed it was only in 1703 that the first Ceylonese tourmaline attracted the attention of Europeans when some Amsterdam children, in playing with stones from a shipment rejected by lapidaries, noticed that when heated by the sun they attracted light objects. Their nonplused parents, when the child's inevitable "Why" was heard, at once dubbed the stones "aschentrekkers" (ash-drawers). Our present name comes from the Ceylonese "Tournamal" which is used by the natives for both zircon and tourmaline.

[64] F. Pisani: Compt. Rendu, 1877, tome 84, p. 1509.
[65] Edwin W. Streeter: Precious Stones and Gems, p. 299.
[66] Amer. Jour. Sci. (3), vol. XXI., pp. 128–30, 1881.
[67] George F. Kunz: California Gems, Jewellers' Materials, etc., 1905.

The tourmalines of Maingnin, Burma,[68] were worked by the Chinese from about 1710 to 1768, but a peculiar international situation interrupted mining. The local kinglet had been promised in marriage a beautiful Chinese princess but a hideous older sister was substituted for the charmer. When the reception committee of ministers, having finished a chicken dinner, met her at some distance from the capital and drew the curtains of her palanquin aside, they were so nauseated by her extreme hideousness that they named the place Nan-Kai-San ("the stream where the fowls' flesh tasted insipid"). Naturally enough the Chinese were *persona non grata* and work almost immediately ceased, and except for sporadic efforts the mines were only again re-opened in 1869; since then they have been operated to date.

Brazilian "emeralds" (green tourmalines) appeared in the European market in the seventeenth century. In 1573 Sebistião Fernandes Tourinho, a citizen of Porto Seguro, Brazil, found in the present state of Minas Geraes the first tourmalines.[69]

R. F. Burton[70] gives the year as 1572. The discovery caused many Paulistas to explore the interior and was the cause of much geographical knowledge. Since the discovery, a certain number have been exported each year, the colors being green, red, and blue.

The tourmaline deposits of Mt. Mica, Paris, Me. were discovered late in the fall of 1820, by two students of mineralogy, Elijah L. Hamlin (a brother of Vice-President Hannibal Hamlin) and Ezekiel Holmes. Returning from a collecting trip, they saw in the upturned roots of a tree a vivid flash of green. That night the winter's snow fell and it was only the next spring that they returned to the spot and found the gorgeously colored gems for which this American locality is world-famous.[71]

Olivine (*Peridot*).—The major portion of the world's supply of olivine from 1580–1350 B.C. to the present time has come from

[68] E. C. S. George: Rec. Geol. Surv. of India, vol. 36, pp. 233–8, 1907–8; T. H. D. La Touche: A Bibliography of Indian Geology.

[69] James Henderson: A History of the Brazil, p. 258. London, 1821.

[70] The Highlands of Brazil, p. 114. London, 1869.

[71] A. C. Hamlin: The Tourmaline, pp. 37–8.

Zebirget (St. John) Island in the Red Sea. The first ruler mentioned specifically by Strabo [72] as mining there is Ptolemy Philadelphus of the 4th Century B.C. Agatharchides (116 B.C.) was the first to describe the mines,[73] although olivine presumably from this source is mentioned in Job XXVIII., v. 19 (5th–4th century B.C.)

Chrysoberyl.—One of the remarkable coincidences of the world's history, if admittedly one of no deep political significance, was the discovery of alexandrite in 1831, on the day the Czarevitch Alexander Nicolojevitch, later Alexander II., became of age. Further, the stone is green by natural, and red by artificial light, thus combining the colors of the Imperial Guard at that time. The locality of the discovery was the emerald mines of Takovaga in the Urals. The mineralogist Nordenskjöld named the mineral after the prince, and among the Russians it has always been a most popular stone. Later it was found in Ceylon, but the native jewellers at first considered it only a superior kind of tourmaline.

Topaz.—Near the emerald mines of Jebel Zebara the Egyptians had topaz mines but we do not know that they antedate the time of the Ptolemies (*i.e.*, B.C. 323).[74] Pliny [75] states that in his time it came from Egypt and India. Ceylon was producing topaz in Jean Baptiste Tavernier's time [76] and it was doubtless one of the sources from which the Romans got topaz. The Saxon deposits of Schneckensteins were mined at least in 1737.[77] Bauer [78] states that the topaz mines of Ouro Preto (formerly Villa Rica), Minas Geraes, Brazil, were found in 1760 and the production at one time amounted to 1800 pounds annually.

The Mursinka topaz locality in the Urals, Russia, was found in 1668, and the topaz mines of Monts Ilmen near Miass by the Cossack, Proutov, in the 17th century.[79] Beryls were later located

[72] *Op. cit.*, vol. III., p. 193.
[73] Agatharch. ζ ζ, pp. 81, 82.
[74] S. H. Ball, *op. cit.*, p. 47.
[75] *Op. cit.*, vol. VI., p. 435.
[76] Travels, vol. II., p. 79.
[77] Zeit. f. prakt. Geol., vol. VIII., pp. 29–30, 1900.
[78] *Op. cit.*, p. 335.
[79] L. De Launay: Geol. et Min. Rich. de l'Asie, p. 577.

They were first exploited by the merchant of Lubeck, Menge, from 1824 to 1826 and thereafter by the government. The Kuchuserken Mountain locality in Transbaikalia was found early in the 1850's.

The Japanese crystal miners at Tano Kamiyama (Omi Prov.) had long known but had rejected the associated topaz, as rock crystal was easier to cut. The mineral's true nature was first recognized in 1877 when shown at the National Exhibition held at Tokio.[80] Topaz as a product of Japan was, however, reported by R. Montgomery Martin[81] in 1847.

Garnets.—The Egyptians and the Greeks, at least to the time of Theophrastus (372–287 B.C), obtained their garnets from Egypt and the north African coast to the west thereof, and the Greeks as well from France near Marseilles and Orchomenos in Arcadia, although the stones from the last locality were not fine. In later Greek and in Roman times India[82] and Ceylon, and to a less extent the Alps, furnished finer material than had previously been available to lapidaries. One infers from Pliny that the Indian garnet industry was an old one in his time, and he mentions Hindoo-made garnet vessels holding one sextarius (a little less than a pint).[83] Rajputana, India, where the garnet industry is very old, may have been one of these ancient sources.

The Bohemian pyrope deposits for several centuries were the principal world's source until about 1888, when the industry was injured by fashion's neglect of the stone and competition by South African pyrope, a by-product of diamond mining. The garnets sought by Italians in the German mountains, as described by Agricola,[84] were doubtless from this district or from nearby Saxony, and in deBoot's time (1609)[85] the Bohemian industry was well established. It may well considerably antedate these years.

80 Tsunashirō Wada: The Minerals of Japan, Tokio, 1904.
81 China: Political, Commercial, Social, p. 287.
82 Strabo: *op. cit.*, vol. III., p. 115.
83 *Op. cit.*, vol. VI., p. 421.
84 De Re Metallica, 1556, Hoover translation, 1912, p. 334.
85 Gemmarum et Lapidum, History, p. 40 and pp. 153–4.

Dr. G. F. Kunz [86] describes a company, "Granaten Gewerkschaft," which in 1715–1716 worked the Bohemian garnet placers; this, so far as I know, was the first gem mining company.

The beautiful green garnet, demantoid, was found first in the gold placers of Nizhne-Tagilsk, the Urals, probably early in the 1850's as it received its name in 1853.

The Cape "rubies" (pyrope) which accompany the pipe diamonds of South Africa were found first in 1870 but only became serious market factors in the succeeding decade. The "Adelaide Rubies" found in the Maude, Florence and Hale rivers, Australia,[87] were responsible for the floating of 24 "ruby" mining companies which joined the limbo of dead mining flotations when the "rubies" were proved to be almandine garnets.

The beautiful rhodolite of Macon Co., North Carolina, was first recognized in 1893.[88]

Turquoise.—The oldest mining on a large scale of which we have adequate record was that for turquoise at Wadi Maghara and Serabit El Khadem on the Sinai Peninsula.[89] Although doubtless in operation prior to 3400 B.C., the first pharaoh whom we actually know to have worked the mines was Semerkhet the 7th king of the first dynasty (about 3200 B.C.), although 50 years earlier Usephais had attempted to conquer the region, doubtless for its mineral wealth. Since then the mines have been worked with varying intensity, and today the Arabs obtain turquoise there. At times in the dynastic days from 2000 to 3000 miners and an escort of over 700 soldiers were employed. The underground stopes are relatively extensive. In certain years the production reached 882 pounds of gems. Copper, iron and manganese ores, and malachite of gem grade were among the by-products. The mines were rediscovered to Europeans in 1845 by Major C. K. McDonald, and he later attempted to work them.

The most famous of the world's turquoise localities is Nishapur, Persia, although it appears to be approaching exhaustion, so far

[86] Trans. A. I. M. E., vol. 21, pp. 241–50.

[87] Bauer: *op. cit.*, page 355.

[88] G. F. Kunz: History of the Gems found in North Carolina, p. 50.

[89] For details see Sydney H. Ball: Eng. and Min. Jour., 1927, pp. 483–5.

as fine material is concerned. The earliest reference to these mines which I have found is of the 9th century. During the Caliphate of Motamid, Amr-ul-Lais was from 878–903 A.D. ruler of Khorasan, but was dismissed. He lingered on at Nishapur which he loved, and the following lines are credited to him.

"Its stones are turquoises, its bushes rhubarb, and its dust, edible clay. How could I leave such a land?"[90] The second to mention Nishapur is the Arab Istakhri, who wrote in 951 A.D.,[91] and the third Ibn Haukal (978 A.D.).[92] As Pogue points out, Ibn-el-Beithar, the famous Arab botanist (1197–1248 A.D.), in giving Nishapur as a locality claims to be quoting Galenus (born 130 A.D.) Also suggestive of the early opening of the mines is the fact that Mohammed-ibn-Mansur (A.D. 1300) states that the richest mine was called Isaac, because Isaac the son of Abraham opened it up. Isaac as an individual probably never existed but the tradition suggests that in Mansur's time the mines were believed to be very old. Also as corroborative evidence we may mention that several of the stones described by Pliny, which well might be turquoise, came from Persia and were popular ornaments among the Persians. In Parthian tombs (Parthia was in modern Khorasan) of the first century of our era, turquoise was extensively used.[93] The Sassanians (226–651 A.D.) used it, and intaglios of this material exist. Indeed Sir John Chardin, writing in 1686, in a rather confused passage apparently states that the mines were found in the time of King "Phirous" (probably Peroz, 457–484 A.D.). Further, in the "Periplus of the Erythraean Sea"[94] (1st Century A.D.) "Callean," probably the equivalent of Pliny's Callaina and perhaps of our turquoise, was exported from Barbaricum, a city on the Delta of the Indus. Even now Persian turquoise reaches the sea at about this locality. Ruy Gonzalez de Chavijo,[95] who was Spanish Ambassador to Tamerlane's court in 1403, was the first European to mention

[90] Sir Percy Sykes: A History of Persia, London, 1921.
[91] Joseph E. Pogue: Mem. Nat. Acad. Sci., vol. XII., pp. 12–13.
[92] *Op. cit.*, p. 215.
[93] H. V. Hilpracht: Explor. in Bible Lands, pp. 506–7, Phila., 1903.
[94] Wilfred H. Schoff: *op. cit.*, pp. 38, 170.
[95] Life and Acts of the Great Tamerlane, Hakluyt Society, 1859, p. 108.

Nishapur and its fine turquoise. While we cannot positively date the Nishapur mines earlier than the 10th century, they were probably open at the beginning of our era, although admittedly the occurrence of other turquoise localities in that part of Asia somewhat clouds the issue.

The American Indians worked turquoise mines in our own Southwest at a number of places before the Spanish arrived. That some of these considerably antedate the discovery of America is shown by the many thousands of turquoise beads and pendants found in Pueblo Bonito, dating from about 900 to 1100 A.D.[96] Antedating the last at least 1000 years are the turquoise pendants from the late Basket Maker village in Chaco Canyon, New Mexico.[97] Turquoise is also prominent in the myths of the people of the southwest (*i.e.*, the Zunis, Pimas, Hopi) suggesting the length of time it has been known to them.

About 1535, De Soto's men found that the Indians of the province of Guasco (probably north of Texas) had turquoise, so that at that time the mines were old enough to have their products widely distributed. In 1539, we know from the account of Friar Marcos de Niza that Sonoran Indians used to travel northward to New Mexico to work in the turquoise mines, and the next year the Indians at the head of the Gulf of California told Captain Fernando Alarchon that the Pueblos dug them "out of a rock of stone."[98] The most famous of these old turquoise mines, at Los Cerillos, New Mexico, were reworked by the Spaniards until 1686, when they caved. From the size of the Cerillos open-cut (over 300 feet wide and 200 feet deep) and of its dumps, covering some 20 acres, and the large trees thereon, some of the latter being considered to be 600 years old, a considerable age for these pits is indicated. George H. Pepper, from country rock attached to some of the Pueblo Bonito turquoise pendants, is satisfied that Los Cerillos was the mine from which they were obtained. There are also ancient turquoise mines presumably of pre-Colombian age in the Burro Mountains (re-located by

[96] Nat. Geog. Mag. Dec., 1929, p. 767.

[97] Frank H. H. Roberts, Jr.: Bur. of Ethnol. Bull. 92, p. 142.

[98] Hakluyt Voyages, vol. IX., p. 300.

Americans on information received from a Navajo), Hachita Mountains, and Jarilla Mountains, New Mexico,[99] Sugar Loaf Peak, Lincoln Co., and Crescent, Clark Co., Nevada; Turquoise Mountain, Cochise Co., and Mineral Park, Mohave Co., Arizona; San Bernardino Co., California,[100] and near La Jara, Conejos Co., Colorado.

Lapis Lazuli.—The ancient source of lapis lazuli is largely a matter of inference. It was commonly used in Egypt in predynastic times (*i.e.*, prior to 3400 B.C.) and was even a more common material among the Sumerians of about the same time. This latter circumstance together with Vernier's statement that the Egyptian word for lapis lazuli, "Khesbet," is of Babylonian origin, suggests an eastern source for the stone. Raphael Pumpelly [101] found lapis lazuli beads in the ruins of Anau I., a Stone Age town in Turkestan. There is but one great source for the material in the east and that is the well known Badakhshan (Afghanistan) locality, and I am reasonably satisfied that the Egyptians and Mesopotamians obtained their material from that source, and this notwithstanding the fact that the Assyrians placed the source in the region of the present Armenia or perhaps Persia, where hills were supposed to consist wholly of the gem. Perhaps this region was an ancient trading center for the Afghan stones. I cannot refrain from quoting a letter written by the ruler of Shupria, near Lake Van, to Esarhaddon (673 B.C.), King of Assyria.[102] "As for the lapis lazuli of which the king, my lord, wrote: 'Let them bring lapis lazuli,' the king, my lord, does not know that I went up after lapis lazuli and as I was bringing the lapis lazuli, the land revolted from me. If it pleases the king my lord, let a considerable force come to secure the lapis lazuli." Physically, the lapis lazuli of the Sumerians and Egyptians apparently resembles that of Badakhstan.

It is stated that as early as the time of Confucius (B.C. 550–480) the Chinese got lapis lazuli from the Tunguses (Mongols

[99] W. E. Hidden: Amer. Jour. Sci. (3), vol. 46, pp. 400–402, 1893.
[100] G. F. Kunz: Calif. Gems, Jewelers' Material, etc., p. 12, 1905.
[101] Reminiscences, vol. II., pp. 793–814.
[102] A. T. Olmstead: History of Assyria, p. 364, 1923.

of Manchuria and Thibet), and the natural source for them to obtain it would be Afghanistan. Pliny gives Media as the chief source,[103] but in this he may have included the Afghanistan mine or he may have referred to some mart through which the Afghanistan lapis lazuli passed. In the "Periplus of the Erythraean Sea," lapis lazuli is given as an export in the first century of our era from Barbaricum, a city on the delta of the Indies. At present it reaches the same region by land routes from Badakhshan.[104] A further suggestive bit, inasmuch as these are lode mines, is the statement by Dionysius Periegetes as to lapis lazuli, "which they detach from the parent rock." The first authors to specifically mention Badakhshan lapis lazuli are the Arabs, Istakri (951 A.D.) and Ibn Haukal (978 A.D.).[105] The first European to visit the locality was Marco Polo (in 1271 A.D.) who states: "There are mountains likewise in which are found veins of lapis lazuli, the stone which yields the azure color (ultramarine), here the finest in the world."[106] The mines are still productive. While admittedly there are weak links in the chain and some are even absent, I think the Afghanistan locality has furnished the majority of the world's lapis lazuli from before 3400 B.C. to the present day.

Jade.—Jade, both nephrite and jadeite, was known to the Swiss Lake dwellers, and jadeite at least to early Upper-Palaeolithic man. Presumably the first source was stream pebbles, and none of the important sources of the present day are believed to be extremely old, since jade was rarely used either by the Egyptian or Mesopotamian jewelers.

There were several ancient sources of nephrite in China. The ancient Geography written by Tshou-li about 1100 B.C. describes the jade mines of Shen-si. Indeed there appear to have been jade sources in that province and in Shan-si certainly in the Chóu and Han dynasties (1121 B.C.–220 A.D.) and perhaps a millenium or so earlier.

[103] *Op. cit.*, vol. VI., p. 432.
[104] Wilfred H. Schoff: *op. cit.*, pp. 38, 170–171.
[105] *Op. cit.*, p. 225.
[106] Travels, p. 84.

The Turkestan nephrite alluvial deposits and rock beds at Khotan were only certainly known a century before the Christian era, although H. T. Chang[107] thinks that China obtained jade from that source in the reign of Huang Ti (2598–2697 B.C.). Certainly Chinese authors writing in the reign of Wuti (B.C. 140–86) mention Khotan jade.[108] Marco Polo[109] (1271–95 A.D.) was the first European to visit the mines, and he comments on the large trade then existing with China.

In the 13th century a Yunnanese trader before crossing into China from Burma picked up a heavy boulder and placed it in his pack saddle to balance his mule's load. When he reached home the rock was found to be jadeite. Attempts to find similar stones were fruitless and yet from time to time jade filtered across the Chinese frontier from Burma. From about 1784 the importation has been large. Prof. W. Griffith, in 1837, was the first European to visit the jade mines. Jadeite in place was only located in the seventies of the last century.[110]

Jade was widely used by the American aborigines. A jadeite tablet found in Costa Rica bears in Maya numerals the date equivalent to 50 A.D., while a nephrite Maya statuette from Vera Cruz has the date corresponding to 100 B.C.

Axes and curiously formed idols of nephrite were used by the Maoris when Tasman discovered New Zealand in 1642. Long known as boulders, it was only found in place about 1900.[111]

Carved nephrite had long been in the possession of natives near Lake Baikal.[112] The explorer and prospector, J. P. Alibert, the discoverer of the graphite mine which bears his name, in 1850 found boulders of nephrite in Onot Creek.[113] The mineral was

[107] Bull. Geol. Soc. of China, vol. I.

[108] Abel-Remusat: Histoire de la Ville de Khotan, p. 2, Paris, 1820; Yule's Marco Polo, vol. 1, p. 177; also Rec. Ind. Geol. Survey, 1874, vol. VII., pp. 51–3.

[109] *Op. cit.*, pp. 97–8.

[110] Holland and Fermor: Rec. Geol. Survey of India, vol. XXXIX., pp. 122–3, 1910; C. W. Chater: Trans. Inst. Min. Eng., London, vol. 49, pp. 630–31, 1914–1915; N. M. Penzer: The Mineral Resources of Burma, 1922; Dr. F. Noetling: India Geol. Survey, vol. XXVI., pp. 26–31.

[111] A. Dieseldorff: Amer. Jour. Sci. (4), vol. XIII., pp. 73–4, Jan., 1902.

[112] Revue Universelle des Mines (3) T. 29, p. 139, 1895.

[113] L. De Launay: La Geologie et les Richesses Min. de l'Asie, p. 92.

found in place in 1897 by L. von Jaszewski, a Russian geologist.[114] The nephrite of Jordansmühl, Silesia, was described by Linnaeus in 1735.[115]

Opal.—The source from which the Romans obtained opal, which they highly prized, is a moot question. Pliny said that "India is the sole parent of the opal," and his statement is supported by the fact that our word "opal" is derived from the Sanskrit word *upala,* "a precious stone." T. H. D. La Touche[116] mentions several Indian localities, but none of these appear important as to either quality or quantity. Several gem authorities suggest that the opals of Hungary were mined in Roman times, carried by merchants to India and thence re-exported to Rome as "Oriental" stones, the price increment warranting the venture, as it certainly did as to other gems in the Middle Ages. The earliest local archives, however, only certainly show that the Hungarian mines were worked in the 14th century. At present Hungary as a source of opals has been almost wholly superseded by Australia.

The large Australian production, particularly that of Queensland and New South Wales, forced down the price of opals, notwithstanding the beauty of the product. The first Queensland opals were found at Listowel Downs in 1872 but the first real activity was in 1878, when an opal mining venture was floated in London.[117] In 1880 the first fine opals were found in Queensland, and in 1889 the famous White Cliffs field, New South Wales, was accidentally discovered. A hunter was tracking a wounded kangaroo when a bright-colored bit of opal float attracted his eye. Other pieces were found nearby and trenching disclosed the gem in place.[118] Since then the production has been more or less continuous.

About 1908, Charles Nettleton, an old gold miner, wandered into the town of Angeldool and was there shown a few stones, and as a result the opal district of Lightning Ridge, New South

[114] Dieseldorff: *op. cit.,* pp. 73–4.
[115] Bauer, *op. cit.,* p. 461.
[116] A Bibliography of Indian Geology, pp. 175–6, Calcutta, 1918.
[117] C. F. V. Jackson: Queensland Geol. Survey Rpt. 177, 1902.
[118] Edward F. Pittman: *op. cit.,* p. 385.

Wales, was discovered. The Stuarts Ridge field, South Australia, was discovered in 1915 (or 1916), and the black opal district of Tintenbar, New South Wales, in 1919 (or 1920).

The fire opal of Mexico was doubtless known to the Aztecs. There is now in the Field Museum, Chicago, a head of the Mexican Sun-God carved in fire-opal and probably the work of an Aztec lapidary. Since the 16th century, it has been in European collections, and was one of the gorgeous gems owned by Philip Henry Hope. Snr. Garcia [119] reports the finding of worked opals in the mountains southeast of Lake Chapola near Tiquilpan Michoocan. There are, in my opinion, two famous word pictures of the opal; first, that of Pliny, who states it to be the most difficult stone to describe, " displaying at once the piercing fire of carbuncle, the purple brilliancy of amethyst, and the sea green of emerald, the whole blended together and refulgent with a brightness that is quite incredible," and second, that of Sahagun's Nahuatl text descriptive of Aztec lapidary work (Seler's translation) which can only refer to opal, as follows: " And that which they call humming bird silex (stone of a thousand colors) is (in color like) an animal of that nature. It is tinted (painted) in a thousand colors, white, blue, clear, brilliant red, black with white spots, and the color of the rainbow. They scrape it and simply polish it with fine sand." [120] When Velasquez painted the portrait of Antonio Eusebio de Cubero, Secretary to Gen. Don Diego de Vargas, Governor of New Mexico about 1692, he portrayed on his fingers a ring with a " fire opal of Zimapan." [121]

The mine at San Juan del Rio near Queratero still produces opals which have a certain sale among tourists to Mexico. A peon found the gem by chance on the hacienda on which he worked in 1835, but systematic work has been carried on only since about 1870.

Von Leonhard (1843) describes the Gracios o Dios (Honduras) opal mines, and they were doubtless known for some

[119] Soc. Mex. Geog. Bol. 2 da epoca T. IV., p. 559.

[120] Marshall H. Saville: Turquoise Mosaic Art in Ancient Mexico, p. 33, New York, 1922.

[121] Susan E. Wallace: Land of the Pueblos, 1888.

time previously. Indeed, Wm. T. Brigham [122] states that the pre-Colombian Quiché procured the opals used in their jewelry from Honduras.

Rock Crystal.—The paleolithic men of France of the Reindeer Age apparently obtained rock crystal from the Auvergne Mountains in France [123] and may well have mined it from quartz veins as the primitive Andaman Inlanders do to this day.[124] The Egyptians had rock crystal pits north of Aswan.[125] Esarhaddon, the Assyrian king, who reigned from 681–668 B.C., conquered the land of Patusharra deep in the Median territory, near the Bikni Mountains, famous for its crystal. India was a Roman source, and ever since has produced a little.[126] Queerly enough, Megasthenes apparently confuses rock candy and rock crystal when he describes stones dug up in India "of the color of frankincense, sweeter than figs or honey." [127] The Swiss and French Alps still produce a little rock crystal and were, according to Pliny, also one of the chief Roman sources. Indeed it was the gem's coolness to the touch and its occurrence among the snows and ice of the Alps that led the ancients to believe it frozen water, hence the derivation of the name from the Greek word for ice.

In Japan rock crystal is supposed to have been obtained for centuries from around Kimpūsan in the province of Kai,[128] and a geography called Fūdoki, published in 714 A.D., states that it was then produced in the province of Mutsu.[129] The Brazil rock crystal deposits have been worked by Europeans for some time; the earliest reference known to me is its production reported by John Nieuhoff in 1643.[130]

The rock crystal of Madagascar has been known for a long time. A. Lacroix [131] states that Arabian sea captains carried rock

[122] Guatemala, p. 256, New York, 1887.
[123] H. N. Hutchinson: Prehistoric Man and Beast, p. 68.
[124] A. de Quatrafoges: The Pygmies, p. 114, New York, 1895.
[125] A. Lucas: Ancient Egyptian Materials.
[126] Strabo: (B.C. 54–A.D. 21), vol. III., p. 115; also Pliny.
[127] Strabo: vol. XV., C–37.
[128] Tsunashirō Wada: *op. cit.*, p. 38.
[129] Mining in Japan, Past and Present, p. 4. Bur. of Mines (Tokio?), 1909.
[130] Churchill, vol. II., p. 30.
[131] Revue Scientifique, vol. 59, p. 356, June 25, 1921.

crystal from Madagascar to Arabia and India in the 9th and 10th centuries. The Dutch Admiral Cornélis Houtman found much rock crystal in 1595 in Antongil Bay. In the 17th century some was exported [132] to France, more in the 18th century, and some is still produced.

Amethyst.—The Egyptians mined amethyst near Gebel Abu Diyeiba in the Safaga district of the eastern desert. They also obtained it from Nubia.[133] The Romans obtained it from the same sources, from Arabia, Ceylon and India. The editor of Nieuhoff's Voyages [134] says the stone had been exported from Brazil since 1727. "Very perfect Amathists" were reported from the province of Rio Plata, the Uruguay of our day, in 1601.[135] The large production of excellent amethyst from the Urals, the Altais, and Brazil, lowered the price of the gem markedly at the beginning of the 19th century, and the necklace of Queen Charlotte of England, priced at the beginning of the 19th century at £2,000, would now be worth but perhaps a percentage of that sum.

Agate.—Agate is relatively so common a mineral that the lapidaries of the ancient peoples first began using pebbles of it from near their homes. The Egyptians, for example, obtained it first from among the pebbles of the Egyptian deserts, and the Etruscans from those of their own Tuscan rivers. The name is derived from the Achates River (now the Drillo) in Sicily, a famous locality in the time of Theophrastus (372–287 B.C.). The Black Sea Coast in the vicinity of Kerasoun and Trebizond produced many fine agates in Roman time and furnished the raw material for Mithridates' famous vases.

The most famous of the old sources was Ratnapur, India, and this furnished much fine material to the Greek and Roman lapidaries. Broach, and later Cambay, were the principal local cutting centers. Ctesias [136] states that in India "there are certain

[132] Abbe Rochon: p. 179.

[133] S. H. Ball: *op. cit.*, p. 47.

[134] Knox: Coll. of Voyages, vol. II., p. 32.

[135] Description of the West Indies, Antonio de Herrara Purchas: His Pilgrims, vol. XIV., p. 547.

[136] J. W. McCrindle: Ancient India as described by Ctesias the Knidian, p. 9, Calcutta, 1882.

high mountains having mines which yield the sardine-stone and onyxes and other seal-stones." He, a physician resident in Persia, obtained his information from Hindoos whom he met at court between 416 and 398 B.C. The industry therefore appreciably antedates 400 B.C. Among the travellers of the middle ages the Indian agate industry is described by Duarte Barbosa[137] (1501–1516), by Ludovico Verthema (1503–1508)[138] and by most of their successors.

Pliny gives Arabia as a source of sardonyx and carnelian in his time and the well known Sanaa, Yemen, locality is mentioned by early Arabian authors, including Teifaschi (1242 A.D.). In Genesis, presumably written in its present form about 500 B.C. is mentioned (Chapter 2, v. 12) the onyx of Havilah (Arabia), so knowledge of the deposits may be relatively ancient. The agates and related semi-precious stones of Idar and Oberstein on the Nahe River, Germany, have long been known, and the cutting industry, one of the most important in the world, dates back at least to the 14th century. Edward H. Kraus[139] states that "according to tradition, as early as 1454 two of the small shops where gems were cut and polished were in need of repair."

The geodes of Paraguay and Argentina were known to Alvaro Alonso Barba,[140] who lived from 1569–1662, and those of the Uruguay-Brazil border to Pedro de Mogalhães de Gaudavo[141] in 1576. Their commercial development was much later, for with the exhaustion of the agates of Idar, scouts were sent out to find a new source of supply. In 1827, emigrants from Oberstein, members of a wandering German band, found in Southern Brazil an agate occurrence resembling that of the homeland.[142] Since then that region and neighboring parts of Uruguay have been the principal source of supply.

Amber.—Amber was known to man early in upper Paleolithic time. The Neolithic men of East Prussia and Denmark prob-

[137] *Op. cit.*, p. 64.
[138] Travels of Ludovico di Verthema, Hakluyt Society, 1863, p. 107.
[139] Dearborn Independent, Nov. 27, 1926, p. 14.
[140] El Arte de los Metales, Chap. 15.
[141] History of Brazil, p. 117, Cortes Soc., 1922.
[142] Kraus: *op. cit.*, p. 14.

ably picked up amber in quantity on the Prussian Coast as early as 7000 B.C. By 1000 B.C. it was an article of trade of the Phoenician merchant and the Greek word for amber, electron, is evidently of Phoenician origin. Further chemical analysis indicates the Baltic source of the amber found in various Aegean sites.[143] Pytheas (340 B.C.) says that in his time the Gluttones, an East Prussian tribe, gathered amber on the Baltic Coast. But the field is in old age and is showing signs of exhaustion.

Sicilian amber, it is claimed, was used by the Swiss Lake Dwellers.[144] The unimportant deposits on the Lebanon coast were worked by the Phoenicians.[145]

The amber mines of Burma were known to the Chinese at an early date, the following statement occurring in the annals of the later Han dynasty (206 B.C.–220 A.D.) "Ai lao (the Chinese name of the ancient Shan kingdom dating from the first century A.D.) produces both pearls and amber."[146] In this connection Pliny (51 A.D.) states[147] "that amber is found in India too is a fact well ascertained," Ctesias (398 B.C.) being the first to mention its occurrence in a river of India. So far as I know Caesar Frederick (1569 A.D.) is the first European to specifically mention Burma amber. S. F. Hanney, in 1836, was the first European to visit the mines.

The amber of the southern Mexican coast was an important article of commerce among the Aztecs, and the amber of Santo Domingo was gathered in pre-Colombian days. It was the first gem material recognized in the New World, as Christopher Columbus in his account of his second voyage says the island contains "mines of copper, azure and amber."[148]

Miscellaneous Ornamental Stones.—Jet was used ornamentally as far back as 16,000 B.C. The Romans are said to have opened

[143] George M. Calhoun: The Business Life of Ancient Athens, p. 14, Chicago, 1926.

[144] Compt. Rendu, Ac. Sc., tome CLII., pp. 421–3, 1916.

[145] S. H. Ball: *op. cit.*, p. 41.

[146] N. M. Penzer: *op. cit.*

[147] *Op. cit.*, vol. VI., p. 402.

[148] History of the Discovery of America by Christopher Columbus, written by his son Don Ferdinand Columbus: Kerr's Voyages, vol. 3.

up the British mines and to have shipped the product to Rome.[149] Solinus (3d century A.D.) mentions Britain's jet. The principal commercial source, Whitby, was mentioned by Caedmon (circum 658–80 A.D.). The Venerable Bede (672–735 A.D.) says Britain "has much and excellent jet" which "when heated drives away serpents." In the Lapidarium of Marbodus (written 1067–1081) is the couplet:—

> Lycia her jet in Medicine commends,
> But chiefest that which distant Britain sends.

Jet is mentioned in the records of St. Hilda's Abbey in 1350, and the monks then made rosaries of it; the first workshops in Whitby were, however, only established in 1808. By 1873 the 200 workshops employed 1500 people, but the material lost its popularity and by 1910 only 30 superannuated workers were still employed.

Malachite was one of the by-products of the Egyptian turquoise mining on the Sinai Peninsula. The famous Ural mines of Nizhne-Tagilsk, Bogoslovsk and Gumeshevsk, were heavy producers at the beginning of the 19th century.

Fluorspar was used by the Romans, and Derbyshire was doubtless one source, as some of the lead mines there in which fluorite is a gangue were worked by the Romans[150] in the 3d and 4th century of our era. The Derbyshire cutting industry was founded in 1765.

The early pharaohs quarried *alabaster* at Wady Gerraiñ near Memphis and Kheops, and their successors got theirs from Hâtnûbû near Hermopolis.[151] The Mesopotamian peoples had their local quarries near Mosul and at Kerkouk, 125 miles north of Bagdad. The Aztecs had quarries of "Mexican onyx" at or near Tecali.

Obsidian was produced on the island of Melos (Modern Milo) at least in the early days of the Aegean civilization. Pliny gives as sources Africa, India, Italy and Portugal. The Egyptianized Greek merchant who wrote the "Periplus of the Erythraean Sea"

[149] Alex Del Mar: Ancient Britain, p. 21.

[150] William Morley Egglestone: Trans. Fed. Inst. of Min. Eng., vol. 35, p. 237, 1907–8.

[151] S. H. Ball: *op. cit.*, p. 47.

in the first century of our era describes an island in the Red Sea from which obsidian was then obtained. Alexander von Humboldt rediscovered the old Aztec obsidian pits of Sierra de las Navajos.[152] From the extent of the pits it is believed that mining began some centuries before the arrival of the Spaniards.[153] Indians also quarried it in other states in Mexico (Jalisco, Michoacan, etc.), in the Yellowstone National Park, New Mexico, Arizona and Guatemala. That it was long in use among certain of the Indians is indicated by the Athabascan folk-tale in which it was one of the four substances existing before the world was created.[154]

26 BEAVER ST.,
NEW YORK CITY.

152 Feuchtwanger: A Popular Treatise on Gems, p. 309, New York, 1872.

153 Edward B. Taylor: Anahuac or Mexico, and the Mexican Ancient and Modern, London, 1861; also W. H. Holmes: Amer. Anthropologist, N. S., vol. 2, 1900, pp. 405–16; A. Breton: Proc. Int. Congress of Americanists, New York, 1902, pp. 265–8.

154 P. E. Goddard: Indians of the Southwest, p. 180, New York, 1927.

TEXTURES DUE TO UNMIXING OF SOLID SOLUTIONS.[1]

G. M. SCHWARTZ.

INTRODUCTION.

THE criteria which enable the student of polished surfaces of ores to interpret the relationships involved have been the subject of more and more discussion as the record of observations has increased. The criteria for various processes have been compiled by the Sub-Committee on "Criteria of Paragenesis of Ore Minerals." Among the textures which cause considerable difficulty in interpretation are those which result from segregation in a solid state or, in other words, the unmixing of a solid solution on cooling.

There seems to be considerable confusion in the use of terms to express the change in a solid solution when lowering of temperature renders the solution unstable and it separates into two phases.

Perusal of metallographic and geologic literature shows that the terms "breakdown," "segregation," "unmixing," "transformation," "precipitation" and "ex-solution" are all used. Objections to some of these terms are apparent as they are more commonly used in connection with other processes. Transformation is a broader term, covering not only the process referred to above, but especially the change of solids from one crystal form to another; for example, chalcocite inverting from the orthorhombic to the isometric form on heating above 91° C.

In metallography the term "unmixing" is used by many authorities. The term "ex-solution" seems to have found favor lately in geologic publications. The term may be used to de-

[1] Contribution from the National Research Council Committee on Processes of Ore Deposition, Sub-Committee on Criteria of Paragenesis of Ore Minerals, E. S. Bastin, Chairman.

scribe the process and by compounding with the word texture may be used as "ex-solution texture" to designate the texture resulting from the process. Both unmixing and ex-solution can be used with a minimum of confusion. They are used interchangeably in this paper.

The same texture as, for example, chalcopyrite blades in sphalerite, has been interpreted by some investigators as replacement and by others as a result of unmixing. In assigning an origin by unmixing of a solid solution to certain textures, earlier workers depended mainly on the analogy of the textures of the ores to those found in artificial metallic alloys. European writers have gone much farther in this respect than American investigators. This is shown especially well by the work of Schneiderhöhn [2] and Van der Veen.[3] Lately the problem has been attacked from the experimental side, using natural specimens as well as synthetic material. This has led to more definite ideas regarding these structures. It is perhaps advisable in formulating criteria of textures due to unmixing to review the characteristics of intergrowths rather definitely known to result from unmixing as well as those of similar intergrowths formed by replacement. The contrast in these characteristics should give us certain tentative criteria which may be useful in determining the origin of such intergrowths by microscopic study. These criteria will remain tentative until a great deal of experimental work has been done and it is to be hoped that experimental data will accumulate rapidly on those cases which are now assigned to unmixing of a solid solution solely on the basis of the microscopic texture.

There has been some attempt to tie up the origin of intergrowths of minerals with the principles demonstrated in the equilibrium diagrams of the phases involved. This is the logical manner of attack but unfortunately the equilibrium diagrams involved in the common ore minerals are almost unknown. Attempts have therefore been made to reverse the above procedure

[2] Schneiderhöhn, H.: Anleitung zur mikroskopischen Bestimmung Mineralien. 1922; Entmischungserscheinungen inner halb von Erzmischkristallen, etc. Metall. und Erz, vol. 19, pp. 501–508; 517–529, 1922.

[3] Van der Veen, R. W.: Mineragraphy and ore deposition. The Hague, 1925.

and infer the nature of the diagram from the structure and occurrence of the minerals. These attempts are based on the assumption that we are reasonably sure of the origin of the intergrowth, an assumption which is certainly unwarranted at the present time. Only when the equilibrium diagrams are worked out experimentally by synthetic mixtures will we be able to speak with anything like finality regarding many of these relationships. Meanwhile the criteria must be based on analogy to known cases, drawn partly from the work of the metallographers. The natural examples must be critically studied and compared with intergrowths of similar appearance but obviously of replacement origin.

TEXTURES.

There are two main types of textures and a third minor type which should be logically considered in a general discussion of the problem of ex-solution textures.

The first is the so-called graphic intergrowth; the second, the more abundant type, is the crystallographic intergrowth in which the crystal structure of one constituent very definitely controls the distribution of the other constituent. This is essentially the Widmanstätten structure of meteorites. The inclusions may be needles, blades or plates; rarely they may be wavy on polished surface. A third type of texture consists of irregular rounded inclusions in crystals or grains, in some cases arranged along crystallographic directions of the enclosing minerals, in other cases irregularly distributed. The graphic and crystallographic intergrowths should be considered separately, since their origin and significance may be quite different.

Schneiderhöhn [4] has classified segregation textures as follows:

1. Emulsion structures. Segregations of submicroscopic to microscopic globules from the parent crystal.

2. Cell, net, or mesh structure, due to the migration to, and accumulation at the boundaries of, the crystalline grains.

3. Lamellar or Widmanstätten structure. Plate and needle-like segregates arranged in the parent crystal according to structural planes of the crystal.

[4] Schneiderhöhn, H.: *op. cit.*, Metall. und Erz., vol. 19, p. 507, 1922.

4. The eutectic structure, consisting of a very intimate grain-like or lamellar intergrowth of two (or more)kinds of crystals.

Graphic Intergrowths.

There is no single microscopic texture found in ores that has been discussed as much as the graphic intergrowth and we are apparently far from agreement regarding its significance. Even the type of texture described as graphic varies greatly with different authors. Some use the term for only those peculiar curved lamellar intergrowths often found in the eutectics of the metals (the eutectic structure of metallography and Lindgren's pseudo-eutectic texture). Others seem to use the term for any sort of intimate intergrowth including the Widmanstätten structure. This confusion and lack of discrimination in the use of these terms is very unfortunate since their significance is usually different. The graphic (eutectic or pseudoeutectic) texture has not been formed experimentally by the unmixing of solid solutions of minerals in so far as the writer is aware. This texture seems to form by replacement in ore minerals, and it may in some cases form by simultaneous deposition, not necessarily an eutectic. It probably forms by unmixing only in the rare cases of eutectoid deposition. There is no authentic case of this known in natural minerals.

The Widmanstätten, or lattice texture (crystallographic intergrowth), on the contrary is the normal result of unmixing and indeed in metallography is considered as a definite indication of unmixing.[5] It should be noted that very similar textures form in ore minerals by replacement. The crystallographic control in this texture, when formed by unmixing, is commonly complete, in which respect it contrasts with the so-called graphic texture where the relation to crystallographic directions is usually poor or not visible at all.

In view of the confusion it may be advisable to adopt new terms for some of these textures, or to re-define those in use.

[5] Mehl, R. F., and Barrett, C. S.: Studies upon Widmanstätten structures. Amer. Inst. Min. and Met. Eng. Tech. Pub. 353, 1930.

Care must be exercised in the use of the present terms and above all in the significance attached to them.

Without considering the view of each author in detail, which would occupy too much space, certain rather categorical statements may be made regarding the graphic or pseudo-eutectic type of intergrowth. It has been considered to form in the following ways:

1. As a eutectic mixture of the two minerals.
2. As a breakdown of a solid solution at the eutectoid point.
3. By contemporaneous deposition of the two minerals not in eutectic proportions.
4. By replacement of one mineral by another, starting perhaps along cleavage.
5. By recrystallization during contact metamorphism.

1. *Eutectic.*—There has been considerable misunderstanding regarding these textures and their possible relations to eutectic deposition. It has been pointed out by Whitehead [6] that in a true eutectic only one phase may be in excess. Examination of the photomicrographs of most of the graphic intergrowths described in ores, especially of chalcocite and bornite, shows both minerals in excess of the possible eutectic intergrowth. They therefore do not represent eutectic deposition. A review of the literature shows a few cases that may be eutectics. The conditions for a true eutectic seem to be fulfilled by the specimen illustrated by Short and Ettlinger [7] (Figs. 16, 18).

An excellent example of a true eutectic pattern is shown by Figs. 97 and 98 of Van der Veen's book. This consists of silver and copper with the copper in excess. By referring to the constitution diagram of the system copper-silver,[8] the composition and fields of stability of the phases in this system may be observed. The copper-silver eutectic has the composition of 28 per cent. Cu and 72 per cent Ag. The excess of only one constituent is ob-

[6] Whitehead, W. F.: The paragenesis of certain sulphide intergrowths. ECON. GEOL., vol. 11, pp. 1–13, 1916.

[7] Short, M. N., and Ettlinger, I. A.: Ore deposition and enrichment at the Magma mine, Superior, Arizona. Trans. Am. Inst. Min. Eng., vol. 74, pp. 174–222, 1926.

[8] International Critical Tables, vol. 2, pp. 421, 1927.

vious in the photomicrographs. In some cases it is possible that a condition of supersaturation may be reached with reference to the minor constituent, but it is improbable that this supersaturation would go very far beyond the eutectic composition, so that cases of this sort should be easily recognized. Van der Veen explains in this manner the narrow rims of the silver component around the copper areas in Fig. 97, referred to above.

2. *Eutectoid.*—The term eutectoid is not a common one in geological literature and it may be advisable to explain briefly its significance. It was suggested by Howe[9] to denote alloys of lowest transformation point as distinguished from the alloy of lowest melting point. Howe says: "The suffix 'oid' clearly in-

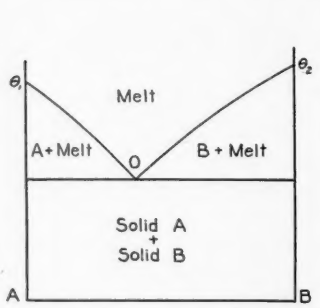


FIG. 1 (left). Constitution diagram of a binary system with eutectic point (o).

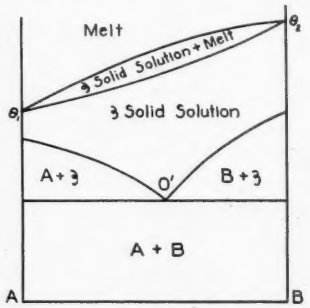


FIG. 2 (right). Constitution diagram of a binary system which forms a solid solution and later breaks down at lower temperatures with eutectoid point (o').

dicates that the eutectoid has the form and other important properties of the eutectic; it keeps the resemblance of the eutectoid to a eutectic before the mind, while it allows us to preserve the initial meaning for eutectic and to distinguish between the two really distinct though related entities." The term is now in common usage in publications on metallography. The eutectoid point corresponds to the eutectic point but represents a transformation in

[9] Howe, H. M.: The Metallographist, vol. 6, p. 249, 1903.

a solid state rather than a change from liquid to solid state. The comparison is clearly shown in Figs. 1 and 2.[10]

No real distinction seems to have been made by metallographers between the character of eutectic and eutectoid textures. A review of the textures shown by ores suggests a possible distinction. Graphic intergrowths produced at the eutectic point apparently do not show a grain structure limiting the lamella, whereas in the case of eutectoid deposition the grain structure prevailed before the breakdown, therefore the graphic texture does not cut across grain boundaries and is differently oriented for each grain (Fig. 3). A comparison of Figs. 64 and 97 in Van der Veen's book will show the distinction. The validity of this criterion needs testing.

3. *Contemporaneous Deposition.*—It has been suggested that the graphic texture may result from simultaneous deposition not at the eutectic proportions of a system. Proof that textures have formed in this manner is lacking and it is difficult to see how conclusive proof may be obtained.

4. *Replacement.*—The origin of graphic intergrowths by replacement can be proven by the criteria indicative of replacement found in the minerals involved in the intergrowth. These criteria are discussed in the report of the Sub-Committee on Criteria of Paragenesis of Ore Minerals. Dr. Lindgren[11] has recently described an example in detail.

5. *Recrystallization.*—The formation of micropegmatite or graphic intergrowths of quartz and feldspar by contact metamorphism has apparently been abundant in places. This may be considered as a process of recrystallization. There is, so far as known, no example of this in ores, but it is shown by sediments metamorphosed by intrusives. Some question has been raised regarding graphic textures originating in this matter, but studies by Dr. F. F. Grout and the writer, of the effect of diabase dikes and sills on the slates, graywackes, and quartzites of the Rove

[10] For students unfamiliar with the various types of constitution diagrams, the writer suggests the explanation in Hoyt's "Metallography," Part I., Principles, Chap. 1.

[11] Lindgren, W.: Pseudo-eutectic textures. ECON. GEOL., vol. 25, pp. 1–13, 1930.

formation in Minnesota, seem to leave no doubt that graphic intergrowths of quartz and feldspar develop in the matrix of the quartzite, for example, and in later stages encroach on the quartz grains; Fig. 18 shows quartz grains that seem to have been much attacked. This suggests replacement as part of the process, but in the matrix it would seem to be mainly recrystallization.[12]

The general problem of the interpretation of graphic texture is of importance not only in ores but in igneous rocks, as emphasized by Fenner.[13] Apparently the significance of these textures in rocks is no more obvious than in ores.

UNMIXING TEXTURES.

There are two types of breakdown of solid solutions. The first, referred to under graphic texture, has a history and a result analogous to eutectic deposition from a melt. The corresponding point is known as the eutectoid. Only a few of the investigated systems of alloys show this sort of breakdown. Most systems break down, or unmix, along a curve of decreasing solubility giving a gradual precipitation resulting in crystallographic, rather than graphic, intergrowths.

[12] Grout, F. F., and Schwartz, G. M.: Minn. Geol. Surv. Bulletin, in preparation, will give detailed descriptions and photographs of this example.

[13] Fenner, C. N.: The Katmai magmatic province. Jour. Geol., vol. 34, pp. 675–771, 1926.

FIG. 3. Allemontite. Graphic intergrowth of Arsenic (black) and antimony (white). Note the granular texture. Allemont, France. × 135. Reproduced from Van der Veen.

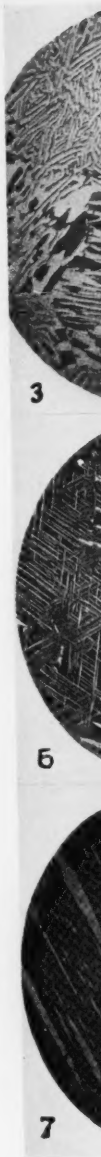
FIG. 4. Blade-like inclusion of ilmenite along octahedral planes of magnetite (etched black). Iron Lake, Minnesota. × 100.

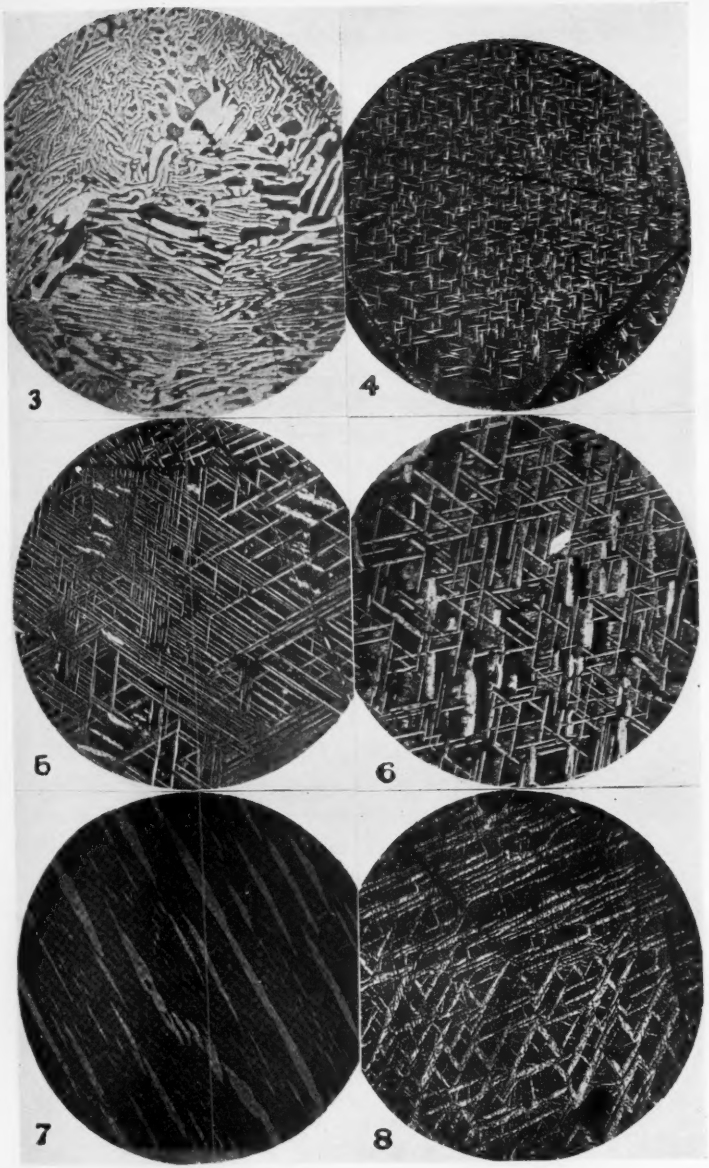
FIG. 5. Closely crowded ilmenite along octahedral planes of magnetite (etched black). Taber Lake, Minnesota. × 100.

FIG. 6. Coarse intergrowth of ilmenite in magnetite. Pillsbury Lake, Minnesota. × 100.

FIG. 7. Ilmenite with hematite intergrowth. Reproduced from Ramdohr. × 210.

FIG. 8. Native silver or solid solution of antimony in silver (etched black) containing blades and lattice of dyscrasite (Ag_3Sb). Cobalt, Ontario. × 65.

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So far as the writer is aware there is no conclusive example of eutectoid structure in ores. Van der Veen cites the case of allemontite (AsSb) but does not give his reasons for so classifying it. Sufficient data on the system arsenic-antimony are not available to warrant such a classification at present.

The writer has artificially produced a texture in a specimen of bornite and chalcocite which suggests somewhat a eutectoid origin.[14] The texture was produced by precipitation from a solid solution, but whether or not it represents a eutectoid of the two minerals can be proven only by detailed knowledge of the system chalcocite-bornite. A similar texture has been observed in a copper ore from Rhodesia.[15]

Proof of the origin of a natural intergrowth of this type would be a distinct contribution to the knowledge of the breakdown of mineral solid solutions.

The breakdown of solid solutions along curves of decreasing solubility is a common phenomenon in metallic alloys and probably in natural minerals. The most common textural result of this type of breakdown is the deposition of the minor component along certain crystallographic planes in the dominant mineral. More rarely the minor component is segregated to grain boundaries or even distinct grains.

REVIEW OF EXAMPLES OF EX-SOLUTION TEXTURES.

The following list of mineral intergrowths affords some evidence that the intergrowths are the result of the unmixing of a solid solution. The first group are indicated by fairly reliable evidence aside from the intergrowth itself.

I. Examples of intergrowths due to unmixing.
   1. Magnetite-ilmenite; 2. Magnetite-spinel; 3. Ilmenite-hematite; 4. Dyscrasite-silver; 5. Chalcopyrite-cubanite; 6. Bornite-chalcocite; 7. Chalcocite-covellite; 8. Pyrrhotite-pentlandite; 9. Chalcopyrite-bornite.

II. Probable or possible examples of unmixing inferred from the texture.

[14] Schwartz, G. M.: Experiments bearing on the origin of chalcocite-bornite intergrowths. ECON. GEOL., vol. 23, pp. 381–397, 1928. See Fig. 10, p. 390.

[15] Schwartz, G. M.: ECON. GEOL., vol. 24, p. 443, Fig. 1.

1. Chalcopyrite-pyrrhotite; 2. Stannite-chalcopyrite; 3. Stannite-sphalerite (both ends of system); 4. Sphalerite-chalcopyrite; 5. Chalcocite-stromeyerite; 6. Bismuthinite-argentite; 7. Galena-argentite and galena-tetrahedrite; 8. Galena-proustite; 9. Galena-stromeyerite; 10. Galena-chalcocite; 11. Stromeyerite-argentite.

III. Examples of somewhat similar textures due to replacement.
1. Chalcocite-bornite; 2. Bornite-chalcopyrite; 3. Covellite-chalcocite; 4. Magnetite-hematite; 5. Sphalerite-chalcopyrite, etc.; 6. Nicollite-chalcopyrite.

Review of Group I.

1. *Magnetite-ilmenite.*—Intergrowths of ilmenite along the octahedral planes of magnetite have been abundantly described and figured.[16] (See also Figs. 4–6, this paper.) Since these ores are found in and normally form a part of a gabbro, the conditions favor crystallization from a melt with the resulting probability of formation of a solid solution. That these intergrowths formed in this way was suggested by Ramdohr from theoretical considerations and from experiments which show that magnetite and ilmenite dissolve at 800 C. to form a homogeneous solid substance.

Recently Kamiyama[17] has reported that Korean titaniferous magnetite shows increased segregation of ilmenite up to 1150° C., but above that temperature the ilmenite appears to dissolve. This involves a decided discrepancy with Ramdohr's results and further work is necessary to clear up the matter.

[16] Singewald, J. T.: The titaniferous iron ores. Econ. Geol., vol. 8, pp. 207–214, 1913; The titaniferous iron ores of the United States. U. S. Bur. Mines Bull. 13, 1913.

Brunton, S.: Some notes on titaniferous magnetites. Econ. Geol., vol. 8, pp. 670–680, 1913.

Warren, C.: On the microstructure of certain titanic iron ores. Econ. Geol., vol. 13, pp. 415–446, 1918.

Ramdohr, P.: Beobachtungen an Magnetit, Ilmenit, Eisenglanz und überlegungen das System FeO, Fe_2O_3, TiO_2. Festschrift zur Jahrfeier der Bergakademie Clausthal, 1925.

Osborne, F. F.: Certain magmatic titaniferous iron ores and their origin. Econ. Geol., vol. 23, pp. 724–761, 1928.

Schwartz, G. M.: The relation of magnetite and ilmenite in the magnetite deposits of the Duluth gabbro. Amer. Min., vol. 15, pp. 243–252, 1930.

[17] Kamiyama, Masatsuyo: Jour. Geol. Soc. Tokyo, vol. 38, 1929.

2. Magnetite-spinel.—Spinel has been found included in magnetite in the same manner as ilmenite and doubtless has in some cases been confused with it.[18] Spinel commonly separates out parallel to the cube faces, as does ilmenite.

Ramdohr [19] has shown that spinel dissolves in magnetite when heated at 1000° C. for twelve hours. The unmixing temperature was inferred from his experiments to be at about 800° C. and the texture resembles that of other intergrowths of magnetite, ilmenite and hematite.

3. Ilmenite and Hematite.—Hematite separates from ilmenite parallel to the base (Fig. 7). In some cases there are two sets of lamellæ. Ramdohr [20] believes that the first is due to a lower solubility of the hematite in ilmenite than existed at the time of formation of the homogeneous mineral and that the second set is due to a change of hematite from one symmetry to another (Fig. 7). Ramdohr observed that the first set disappeared on heating at above 700° C. and the second set at 500° to 600° C.

It seems probable that the intergrowths of hematite and ilmenite result from unmixing and belong in the same category as magnetite-ilmenite intergrowths.

4. Dyscrasite-silver.—One of the few examples of natural crystallographic intergrowths for which a nearly complete equilibrium diagram of the two elements involved *i.e.*, silver and antimony is available. Etching of some supposed native silver specimens shows a remarkable crystallographic intergrowth of two minerals (Figs. 8–9). Tests and analyses show these minerals to be dyscrasite (Ag_3Sb) and native silver (actually a solid solution of antimony in silver). Analyses and reference to the diagram have explained [21] the origin of this intergrowth as due to the breakdown of a solid solution forming the intermetallic compound Ag_3Sb and the solid solution of antimony in silver. Blades of dyscrasite rest in a groundmass of the silver-rich solid solution.

[18] Warren, C. H.: *op. cit.*, p. 430.

[19] *Op. cit.*

[20] Ramdohr, P.: *op. cit.*, p. 350.

[21] Schwartz, G. M.: Dyscrasite and the silver-antimony constitution diagram. Amer. Miner., vol. 13, pp. 495–503, 1928.

Ag_2Sb is formed by a peritectic reaction at 560° C. over certain ranges of composition.

5. *Chalcopyrite-cubanite.*—Crystallographic intergrowths of chalcopyrite and cubanite (chalmersite) have been described from a considerable number of regions.[22] These intergrowths are normally found as laths or blades of cubanite in chalcopyrite, obviously arranged along crystallographic directions (Fig. 10). The blades are characterized by very sharp straight boundaries and lack of continuity. Etching shows that the blades commonly end sharply at the boundary of the chalcopyrite grains. Fig. 10 shows a typical natural intergrowth, and Fig. 11 an intergrowth produced by slowly cooling a solid solution of the two minerals. A natural intergrowth very much like this artificial one has recently been figured by Erimesco.

The fact that intergrowths have been produced experimentally leaves little doubt as to the origin of natural intergrowths of chalcopyrite and cubanite. The detailed description of the experiments is given in the paper cited above.

6. *Bornite-chalcocite.*—The relations of chalcocite and bornite are varied and complex and present a difficult problem as noted in the discussion of graphic intergrowths. A study of the extensive literature dealing with these minerals shows that the chalcocite and bornite occur together in the following ways:

1. Grains or masses of each mineral (ice cake structure, mutual boundaries, etc.).
2. Graphic intergrowths (and subgraphic).
3. Lattice or triangular intergrowths.
4. Blades or plates of bornite in chalcocite.

[22] Schwartz, G. M.: Chalmersite at Fierro, New Mexico, with a note on its occurrence at Parry Sound. ECON. GEOL., vol. 18, pp. 270–277, 1923.

Ramdohr, P.: Beobachtungen am Chalmersit. Metall und Erz, vol. 22, pp. 471–474, 1925.

Schwartz, G. M.: Intergrowths of chalcopyrite and cubanite. ECON. GEOL., vol. 22, pp. 44–61, 1927.

Ramdohr, P.: Neue mikroskopische Beobachtungen am Cubanit, etc. Zeit. f. prakt, Geol., vol. 36, pp. 169–178, 1928.

Thomson, E.: Canadian localities for chalmersite. University of Toronto Studies. Geol. Ser. 24.

Erimesco, P.: Microscopic examination of ores. Eng. & Min. Jour., Nov. 24, 1930, p. 529.

An additional type, possibly a eutectoid mixture in a triangular network of chalcocite, has been produced by the writer [23] on slowly cooling a solid solution of the two minerals. A natural specimen from Mufulira, Rhodesia, has an almost identical structure.[24]

Of the above types numbers 3 and 4 are probably a result of the unmixing of a solid solution, as shown by the experiments described in the paper cited above. Figs. 2, 3, 5, 6, 9 and 10 of the same article show typical examples of these intergrowths, both natural and artificial.

Ray [25] has shown recently that the temperature of solution in bornite-chalcocite is apparently lower when water is placed in a closed system with the specimens.

7. *Chalcocite-covellite.*—Results of extensive work on chalcocite and covellite were published by Posnjak, Allen and Merwin.[26] It was shown that covellite dissolves in chalcocite to a marked degree and remains so at room temperature. Recently Bateman [27]

[23] Schwartz, G. M.: Experiments bearing on bornite-chalcocite intergrowths. ECON. GEOL., vol. 23, pp. 381–397, 1928. A new intergrowth of bornite and chalcocite. ECON. GEOL., vol. 24, pp. 443–444, 1929.

[24] *Op. cit.*, ECON. GEOL., vol. 23. See Fig. 5, p. 389.

[25] Ray, James C.: Synthetic sulphide replacement of ore minerals. ECON. GEOL., vol. 25, pp. 433, 451. 1930.

[26] Posnjak, R., Allen, E. T., and Merwin, H. E.: The sulphides of copper. ECON. GEOL., vol. 10, pp. 492–535, 1915.

[27] Bateman, A. M.: Some covellite-chalcocite relationships. ECON. GEOL., vol. 24, pp. 424–439, 1929.

FIG. 9. Lattice and segregation to grain boundary of dyscrasite in silver. Same specimen as Fig. 8. × 65.

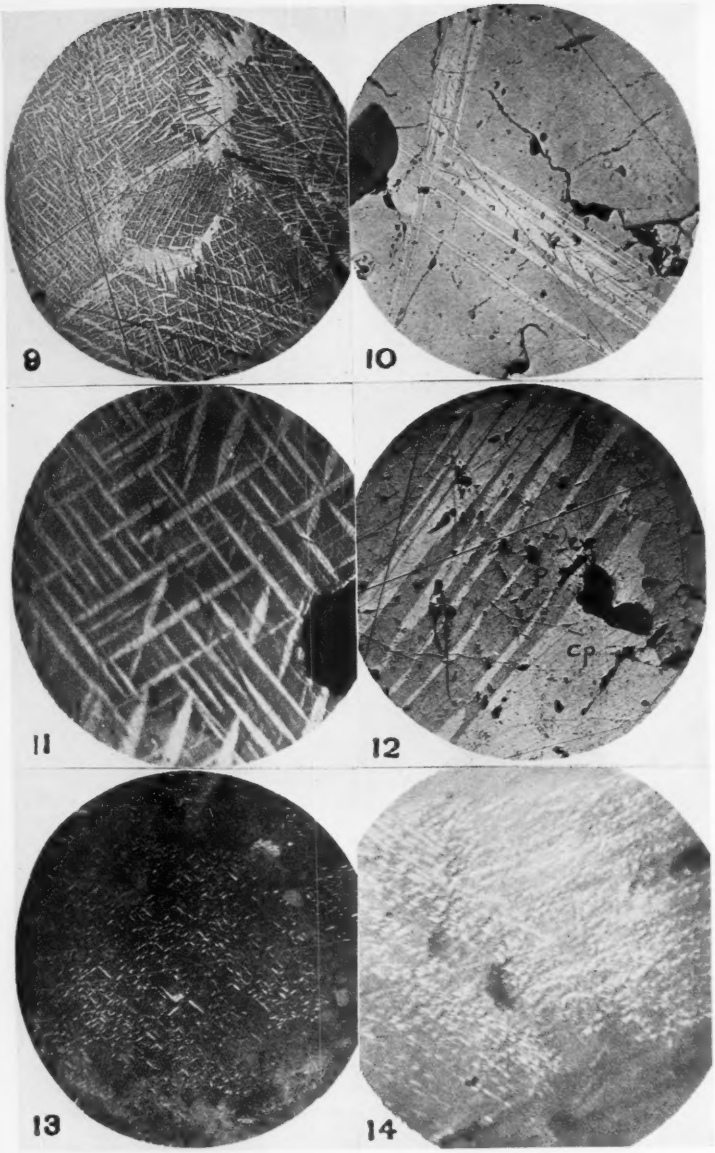
FIG. 10. Cubanite blades oriented in two directions in chalcopyrite. Wilcox Mine, Parry Sound, Ontario. × 50.

FIG. 11. Specimen of cubanite-chalcopyrite ore from Fierro, New Mexico. Heated to 650° C. Quenched, reheated, and cooled slowly. Light blades are cubanite along crystallographic planes in chalcopyrite. × 650.

FIG. 12. Bladed intergrowth of pyrrhotite (*p*) and chalcopyrite (*cp*). Sulphide vein in diabase. Cook County, Minnesota. × 65.

FIG. 13. Stannite with chalcopyrite blades oriented along crystallographic directions. Cornwall, Eng. × 150.

FIG. 14. Chalcopyrite (white) inclusions in sphalerite. Greenback Mine, Leadville, Colorado. × 600.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has reported experiments bearing on mixtures of chalcocite and covellite. He showed that covellite would dissolve in chalcocite on heating at relatively low temperatures, and that unmixing can be induced by annealing. An excellent photograph is shown of lath-like crystals of covellite in chalcocite from Kennecott, Alaska. The experiments also indicated that although covellite would readily dissolve in an excess of chalcocite, chalcocite would not dissolve in an excess of covellite. It was also noted that covellite would dissolve in either the orthorhombic or isometric forms of chalcocite. The chalcocite always adopted the isometric form if heated above 91° C., the inversion point determined by Posnjak, Allen and Merwin. The unmixing experiments were successful with only a few specimens. Bateman is, however, of the opinion that natural specimens showing laths of covellite in chalcocite are due to unmixing.

8. Pyrrhotite-pentlandite.—Newhouse [28] has investigated the relations of these minerals and constructed an equilibrium diagram determined by artificial melts. Pyrrhotite may contain up to 13 per cent. nickel or pentlandite in solution on crystallization. At lower temperature, not determined but in the neighborhood of 600° C., according to the diagram the solid solution breaks down and small lens-shaped masses are formed within the pyrrhotite crystals and along the border of these crystals. Van der Veen [29] had previously assumed from a study of polished ores that pentlandite was dissolved in pyrrhotite at higher temperatures and precipitated out on cooling. His opinion seems amply justified by Newhouse. With sufficiently slow cooling Van der Veen suggests that the pentlandite is completely eliminated from the pyrrhotite, forming grains and stringers along the boundaries of the pyrrhotite grains as illustrated in his Fig. 15. Unmixing textures of this sort have been produced artificially by the writer, using chalcopyrite and bornite. Van der Veen shows a photograph of a wavy intergrowth of two varieties of pyrrhotite which may be an example of unmixing and is so considered by him.

[28] Newhouse, W. H.: The equilibrium diagram of pyrrhotite and pentlandite and their relations in natural occurrences. ECON. GEOL., vol. 22, pp. 288–299, 1927.

[29] Van der Veen, R. W.: Mineragraphy and ore deposition, p. 25. The Hague, 1925.

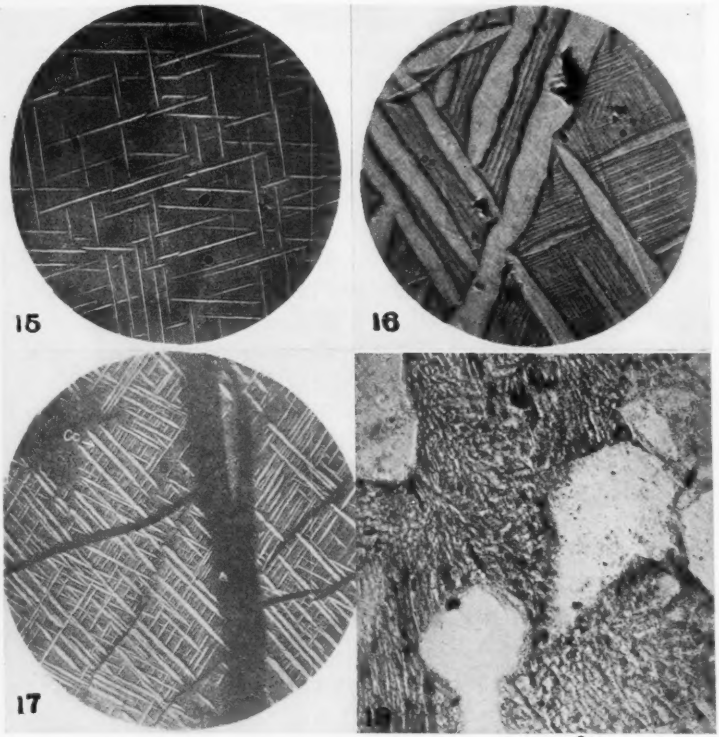

FIG. 15. Chalcopyrite blades in bornite. Specimen from Globe, Arizona. Heated at 500 degrees centigrade for 72 hours. This area formerly bornite only. × 180.

FIG. 16. Chalcopyrite (white) and bornite as a lattice intergrowth. Note that the chalcopyrite blades contract at intersections. Same specimen as Figure 22. × 630.

FIG. 17. Chalcopyrite blades (white) in bornite. Note narrowing of blades at intersections. Reproduced from Geijer. × 430.

FIG. 18. Contact-metamorphosed graywacke. Graphic intergrowth of quartz and feldspar developing around quartz grains and encroaching on them. Cook County, Minn. × 112.

9. Bornite-chalcopyrite.—Schneiderhöhn [30] was perhaps the first to assign intergrowths of chalcopyrite lamellæ parallel to the crystallographic directions of bornite to an origin by segregation from solid solution. Later Geijer [31] and Van der Veen have given examples of this texture. Fig. 7 of Geijer's paper is especially good (Fig. 17). There is difficulty in this case, since chalcopyrite commonly replaces bornite along the cleavage, producing a somewhat analogous texture, as may be observed in numerous published illustrations. There are, however, distinct differences, as for example, the relation to veinlets, cracks, or grain boundaries. Characteristics of replacement are absent in the texture figured by Geijer. The sharpness of the blades, their discontinuity, the fact that they narrow rather than enlarge at intersections, strongly indicate their origin by unmixing.

The writer found on heating specimens of bornite and chalcopyrite intimately mixed that diffusion takes place, resulting in a lattice type of intergrowth as shown in Figs. 15 and 16. Later experiments [32] proved that chalcopyrite and bornite form a solid solution at high temperatures and then segregate out on cooling to form lattice intergrowths. If cooling is slow, segregation to grain boundaries and to distinct grains takes place.

It should also be noted that Van der Veen [33] refers a graphic intergrowth of chalcopyrite and bornite to eutectoid deposition, without, however, giving any evidence other than the graphic structure.

Review of Group II.

1. Chalcopyrite-pyrrhotite.—A crystallographic intergrowth of chalcopyrite and pyrrhotite practically identical with that of chal-

[30] Schneiderhöhn, H.: Entmischungserscheinungen innhalb von Erzmischkristallen, etc. Metall und Erz, vol. 19, pp. 501–508, 517–526, 1922.

[31] Geijer, Per: Some Swedish occurrences of bornite and chalcocite. Sver. Geol. Unders. Arsbok 17, 1923.

Van der Veen, R. W.: *op. cit.*

See also Guild, F. N.: Amer. Miner., vol. 9, pp. 201–204, 1924.

[32] Schwartz, G. M.: Intergrowths of bornite and chalcopyrite. ECON. GEOL., vol. 26, pp. 186–201, 1931.

[33] *Op. cit.*, Fig. 64.

copyrite and cubanite has been described by the writer (Fig. 12).[34] The general occurrence and striking analogy with the experimentally proven case leaves little doubt that this texture is of the same origin. The pyrrhotite is oriented along the same directions in the chalcopyrite and the blades and laths are equally sharp and definite.

2, 3. Stannite-chalcopyrite and Stannite-sphalerite.—The relations of the inclusions in stannite have been rather exhaustively treated by Reinheimer.[35] Schneiderhöhn[36] and Van der Veen[37] have also cited these minerals as furnishing examples of crystallographic intergrowths formed by segreation from a solid solution. There has been no experimental evidence published thus far, so that the true relation remains open to doubt. Preliminary experiments by the writer indicate that chalcopyrite dissolves very slowly in stannite at 500° C.

Chalcopyrite occurs as dots and as well oriented blades in stannite (Fig. 13). Sphalerite occurs mainly as very small dots without orientation. Some stannite specimens show veinlets of chalcopyrite with inclusions of the types described. This throws some doubt on the origin of the inclusions. Since the inclusions are neither more nor less abundant near the veinlet, it is doubtful if they represent replacement from it and they may tentatively be considered as textures due to unmixing.

4. Sphalerite-chalcopyrite.—Inclusions of chalcopyrite in sphalerite have received considerable study. Teas[38] especially examined a great number of sphalerite specimens showing various inclusions of chalcopyrite, and concluded that the chalcopyrite replaces sphalerite. Schneiderhöhn,[39] on the other hand, considers the chalcopyrite globules and laths the result of a break-

[34] Schwartz, G. M.: A sulphide diabase from Cook County, Minnesota. ECON. GEOL., vol. 20, pp. 261–265, 1925.

[35] Reinheimer, S.: Chalkographische Untersuchung am Zinnkies. Neues Jahrb. für Miner., vol. 49, pp. 159–184, 1923.

[36] *Op. cit.*

[37] *Op. cit.*

[38] Teas, L. P.: The relation of sphalerite to other sulphides in ores. Trans. A. I. M. E., vol. 49, pp. 68–82, 1918.

[39] *Op. cit.*, Metall. und Erz, p. 68.

down and found support for this theory in a specimen from a furnace at the Tsumeb mine in German Southwest Africa. Van der Veen also took this view of the origin, but Newhouse [40] has described a specimen from Clear Creek, Colorado, which seems to show that in some cases these inclusions are due to replacement. The writer has heated sphalerite with chalcopyrite inclusions at various temperatures up to 650° C. for three days without dissolving the chalcopyrite. For the present it seems that specimens showing inclusions lacking relations to veinlets or to grain boundaries, may doubtfully be considered to result from a breakdown (Fig. 14). Some examples may very well have formed by replacement and these should be judged by the criteria listed in the report of the Sub-Committee on Paragenesis of Ore Minerals.

5. Stromeyerite-chalcocite.—Guild [41] has described and illustrated an intergrowth of stromeyerite ($Cu_2S.Ag_2S$) and chalcocite (Cu_2S) and suggested that it might have been formed by the breakdown of a solid solution, by replacement, or by recrystallization of a metacolloidal material.

The close resemblance of the texture shown by Guild in his Plate 13-B to the texture secured by the writer [42] by the unmixing of a bornite-chalcocite solid solution suggests that the first explanation is a real possibility. Here again experimental data are necessary before any very definite conclusions may be drawn.

6. Bismuthinite-argentite.—The mineral known as lillianite from its discovery in the Lillian mine, Leadville, Colorado, has been shown [43] to be an intergrowth of bismuthinite and argentite with a typical unmixing texture. The texture in this example [44] is so characteristic that it may be tentatively considered to have

[40] Newhouse, W. H.: Intergrowths of certain minerals. ECON. GEOL., vol. 21, pp. 68–70, 1926.

[41] Guild, F. N.: A microscopic study of the silver ores and their associated mineralization. ECON. GEOL., vol. 12, pp. 298–340, 1917.

[42] Schwartz, G. M.: Experiments bearing on bornite-chalcocite intergrowths. ECON. GEOL., vol. 23, pp. 381–397, 1928.

[43] Emmons, S. F., Irving, J. D., and Loughlin, G. F.: Geology and ore deposits of Leadville. U. S. Geol. Survey Prof. Paper 148, 1927.

[44] See Plate 53, U. S. Geol. Survey Prof. Paper 148, for illustrations.

originated by ex-solution. Preliminary studies by the writer of bismuth-bearing ore from Leadville have also shown examples of the cell or net type of texture.

7–11.—Galena Intergrowths.—Certain other examples of inclusions of one mineral in another have been suggested as examples of segregation. Schneiderhöhn lists segregations of argentite and argentiferous tetrahedrite in galena. The writer is unable to find any conclusive evidence for these examples. Certainly the work of Nissen and Hoyt [45] on galena and argentite does not prove a breakdown. A small amount of argentite remains in solution at room temperature and the rest may gradually separate on crystallization of the minerals.

Guild [46] has recently shown an intergrowth of galena and proustite which he suggests may be the result of unmixing. The texture resembles the graphic intergrowth. Guild also records having found almost exactly similar intergrowths of galena and stromeyerite, galena and chalcocite, and stromeyerite and argentite which, it is also suggested, may be the result of unmixing.

DISCUSSION

A review of the work on unmixing of solid solutions indicates that the most authentic examples show a crystallographic intergrowth as a result of unmixing. There are several reasons for believing that this is the logical result of a breakdown as recently noted by Desch.[47] He explains the breakdown as follows:

> Changes may occur during the cooling down of a solid solution of either of these types. The capacity of the space lattice for holding the second kind of atoms may diminish, so that a constituent is thrown out from solution, just as when a liquid solution has become supercooled. In such a process, the varying properties of different planes within the crystal must again make themselves felt. Deposition will not take place uniformly throughout the crystals, but preferentially along certain planes,

[45] Nissen, A. E., and Hoyt, S. L.: On the occurrence of silver in argentiferous galena. ECON. GEOL., vol. 10, pp. 172–179, 1915.

[46] Guild, F. N.: The enrichment of silver ores. The Laboratory Investigation of Ores, Chap. XI. McGraw-Hill, 1928.

[47] Desch, C. H.: The chemical properties of crystals. Jour. Inst. of Metals, vol. 39, pp. 411–430, 1928.

which are as a rule the most densely packed planes. A familiar example is that of the Widmannstätten figures in meteorites and large masses of steel. Here a constituent is expelled from solution in a face-centered cubic lattice, and the direction of the deposit of kamacite in the one case and of ferrate in the other is parallel with the octahedral planes which are precisely the most densely packed. The β alloy in the copper-aluminum series probably has a bodied centered cubic lattice, and deposits the α phase during cooling along its cube planes. Similar figures are produced in many alloys, as, for instance, those of gold and magnesium, in which they reach great perfection. Whether the formation of the figures be due to changes in solubility alone or involves chemical forces, the effects are of the same kind.

A more detailed explanation with examples is now being worked out and the first paper has been published by Mehl and Barrett.[48]

An explanation of the reasons for oriented intergrowths has been suggested by Gruner.[49] Gruner considered the known space lattices of mineral intergrowths and found that intergrowth occurs only on those crystallographic planes in which the atomic arrangement and spacing are almost alike. At least one of the chief chemical constituents of the two minerals is found in both and there is good reason to believe that one of the structural planes is shared by both minerals. In the examples considered the common contact plane seems to be an oxygen or sulphur plane. It would not matter, of course, whether the intergrowth formed by ex-solution or by replacement.

Some of the suggested examples of ex-solution show rounded or irregular inclusions disseminated either evenly or unevenly throughout the host mineral as, for example, argentite in galena, chalcopyrite in sphalerite (Fig. 14), and chalcopyrite and sphalerite in stannite. This is the emulsion texture of Schneiderhöhn. There is in most of the cases no apparent evidence that they have not formed in other ways. Under the circumstances their origin must be judged not from this texture alone, but from all associated textures and minerals applying the criteria for other modes of origin.

[48] Mehl, R. F., and Barrett, C. S.: Studies upon Widmanstätten structure. Amer. Inst. Min. and Mech. Eng. Tech. Pub. 353, 1930.

[49] Gruner, J. W.: Structural reasons for oriented intergrowths in some minerals. Amer. Min., vol. 14, pp. 227–237, 1929.

A somewhat similar situation exists for the so-called cell or net structure of which pyrrhotite and pentlandite, and magnetite and ilmenite furnish examples. Van der Veen used a hypoeutectoid steel showing a net texture for comparison with the pyrrhotite-pentlandite relation but an examination of his Figs. 14 and 15 indicates that the analogy is only very general and not very convincing. The texture illustrated in his Fig. 15 would doubtless develop if pyrrhotite solidified slightly ahead of pentlandite. Similar textures are common in the titaniferous magnetites, and the writer has recently formed this texture artificially by heat treatment of chalcopyrite and bornite.

The foregoing review, while not necessarily complete or detailed, indicates that the most common texture resulting from ex-solution is a crystallographic intergrowth (lattice or Widmanstätten). Other textures result, but these are probably not common in ores and in the present state of knowledge reveal no characteristics which definitely set them apart as a result of ex-solution. Therefore the problem at present seems to resolve itself mainly into distinguishing between crystallographic intergrowths that result from unmixing and those that form in other ways, particularly replacement. The following criteria are suggested by the studies made thus far. They are in no sense final but may be worth testing by future work.

POSSIBLE CRITERIA.

Criteria for Ex-Solution.—Criteria for ex-solution or unmixing of a solid solution along a curve of decreasing solubility producing a crystallographic intergrowth of widely and uniformly distributed minute inclusions. The crystallographic control is very definite.

1. Inclusions of blade, plate, or rod-like forms characterized by sharp, smooth boundaries. No enlargement where blades cross as in a veinlet; often a contraction at intersections.

2. Lack of relation of included mineral to grain boundaries, veinlets, cracks, mineral contacts, and other localities where replacement characteristically takes place. Even distribution of

inclusions. Not more abundant at grain boundaries or along veins. May even be less abundant at outside of grains. (Same would hold for replacement, except merging at contacts of grains of host.)

3. Lack of criteria of replacement for regular or oriented mineral intergrowths suggests possibility of ex-solution. Any positive criterion of replacement is a negative criterion of ex-solution.

4. Absence of the included mineral outside of the intergrowth. If included mineral is also present outside of the intergrowth it becomes indication either for or against ex-solution origin, depending on its occurrence. Examples: as veinlets, indicative against ex-solution; as contemporaneous grains, indicative of ex-solution.

5. Included mineral usually as disconnected units rather than a network as in replacement along cleavage.

6. Orientation of blades, differs for each grain of the host mineral, dependent on relation of polished plane to crystal orientation.

7. General similarity of the components in chemical and crystal structure. This indicates *a priori* possibility of the mineral forming a solid solution at higher temperatures. Inversions are, of course, important.

Criteria for a Eutectic Texture.—1. Graphic or allied type of intergrowth with or without one mineral in excess; but not with both in excess. Very clear evidence of supersaturation with respect to minor component, which then may occur as narrow rims of minor component around areas of component in excess of eutectic composition.

2. Grains often indistinct and marked mainly by change in nature of graphic texture.

3. General evidence from study of deposit that the minerals were introduced simultaneously.

4. General evidence from the equilibrium diagram of the constituents, if diagram has been worked out.

5. Absence of criteria indicating replacement or origin other than eutectic deposition.

Criteria for Eutectoid Texture.—1. Nos. 1, 3, 6, 7, 9 of the criteria of ex-solution, and Nos. 1, 3, 4 of criteria for eutectic texture.

2. Graphic texture with distinct grain structure, with intergrowth confined within grain boundaries and differing in orientation for individual grains.

3. If one phase is in excess, its grains are of general size and shape of the eutectoid grains.

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THE GEOMETRICAL PATTERN OF CONTACTS IN DETERMINATIVE PARAGENESIS.

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WHAT may be termed the geometrical pattern of contacts constitutes an important instrument in the hands of the ore-microscopist for determining paragenesis.[1] Judging by mineral relations in one plane—and the microscopist is thereto confined,—it may often be said that as a line, determined by the intersection of the plane of contact of two minerals and the plane of polish, turns to the right or left, so one of those species is the older or they are of the same age. That is, this generalization holds in so far as paragenesis is deducible from the geometrical pattern.

Contacts may be classified as of two kinds, *i.e., curved contacts,* which are devoid of angular vertices; and *angular contacts,* which are distinguished by the presence of a greater or less number of such vertices. The intergrowth contact exemplifies the first. An instance of the second is the " wedge vein," which tapers to a point.

CURVED CONTACTS.

These in principle may be reduced to two types: one, the clockwise or counter-clockwise curve, the other, the combined clockwise and counter-clockwise curve. There is, in addition, the straight line, which may be assigned to this category, if it is conceived of as a line with zero curvature. If a contact is evenly curved, that is, constitutes the arc of a true circle, no decision can be made as to the relative ages of the mineral within the circle and that outside of it. The regular serpentine contact, in which an even curve is alternately reversed, belongs to the type of

[1] It should be kept in mind that the geometrical pattern is only one of several means of determining paragenesis. To appreciate the significance of this factor it is necessary to divert attention from these other tools, and concentrate on two minerals in contact, the identity of both of which is unknown.

"mutual contacts"; it affords no evidence as to which is the older of the two species whose plane of junction forms the serpentine. Similarly, the straight contact is mutual in the sense that the mineral on neither side of the contact has the right, from the evidence at hand, to claim that plane of junction as its boundary existing prior to the deposition of the mineral on the other side.

In the above cases reference is made to ideal curves and to the straight line, that is, to contacts which may be expressed in terms of geometrical formulæ. Obviously, these rarely occur in nature with the exception of the straight line, which may be developed in instances of replacement of cleavage or crystal-structure, or in cases where euhedral individuals are covered by a later-depositing species. The contact, in departing from this straight line, may pursue a curve, or may form with that straight line an angle of any size. The latter is considered later. If the departure is at a curve, with which the straight line is in tangential relations, there is no means of discovering from the form of the contact whether the species within the arc is older or younger than that outside. Such a curve-and-tangent contact will, of course, be as rarely met with in practical microscopy as the true arc or true serpentine curve.

Suppose the curves as mentioned above depart from symmetry and cease to be subject to mathematical formulation. Moreover, let it be assumed that the contact, after pursuing a general direction (either curved or straight) for some distance, does not double back upon itself at a sharp arc and follow a direction at something like 180° to its original. What can be said of the age-relations of two species whose contact, never describing a true arc or circle, yet bends constantly either clockwise or counter-clockwise? Obviously, this is a commonly-observed type. We may exemplify it by the well-known chalcopyrite blebs in sphalerite (Fig. 1). Such of these as possess no embayments, but curve at various degrees, always in one sense or the other approximate a geometrical circle, though they rarely, if ever, attain it. From the pattern of the contact they afford evidence neither one way nor the other as to which is the host- and which is the guest-species. Chalcopyrite blebs are usually considered as either contempo-

raneous with, or later than, the blende in which they occur, but there is no reason, from the nature of the bleb-sphalerite contact, that the chalcopyrite should not be called earlier.

Instances in which the serpentine type of contact conforms to mathematical law are, of course, purely fortuitous. But an infinite variety of curves of this general type does exist. Indeed, it may be said that this contact design is perhaps the most commonly met with of all. If we, as before, except for the present that instance of serpentine curve in which a general direction is maintained for some distance and then sharply departed from (somewhere near 180°), what can we say of the relative ages of the two mineral species whose junction-plane forms the serpentine? On the whole the evidence is largely negative. At any given point one mineral forms an embayment in the other, but an embayment furnishes no evidence for determining paragenesis. Moreover, just beyond, the second species forms an embayment in the first. Even if the embayment is nearly closed at its entrance (the hour-glass or bottle-necked form), providing the neck is not long relatively to its width, it is impossible to say whether the surrounding or the surrounded mineral is the older. This sort of contact is represented in Fig. 2.

If the contact has considerable or relatively great length, it will commonly, if not generally, happen that all the forms of contact above-mentioned will be encountered. Thus, after pursuing a series of reversed curves, it may bend at various degrees in either a clockwise or counter-clockwise direction for some distance, and then for a space follow a line that is more or less straight. The contact may be, in short, as intricate as a railroad line following a curved river. Throughout, however, as far as the geometrical pattern of the line of junction of the two species is concerned, no decision can be arrived at with respect to their relative ages.

Curved Contacts of Elongated Bodies.—Thus far we have excepted the case of a contact which, after pursuing a general direction for a considerable space, suddenly turns and bends back upon itself at an angle somewhere near or at 180°. This sort of curve results in an appendage, if attached to a larger body, or in an

isolated body, if a unit itself surrounded by the other species. The thing to be noted about it in either case is that *it is relatively long with respect to its width.* This sort of geometrical pattern, it may be said, of all possible forms, is the only one which offers

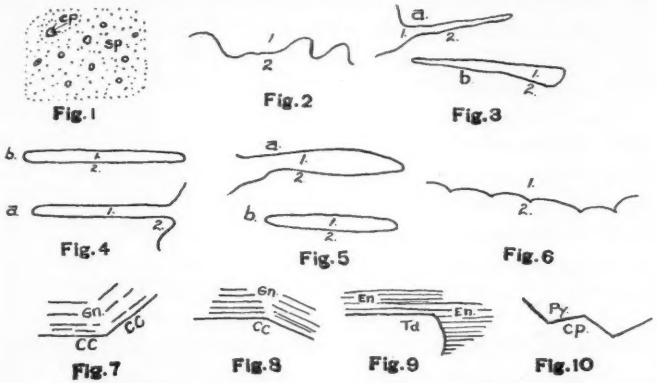


FIG. 1. Rounded chalcopyrite (*cp*) blebs in sphalerite (*sp*). Age relations not apparent. Roughly × 100.

FIG. 2. Irregular serpentine contact. Age relations not apparent.

FIG. 3. Wedge type of elongated body. Appendage (*a*), unattached (*b*).

FIG. 4. Worm type of elongated body. Appendage (*a*), unattached (*b*).

FIG. 5. Ellipsoid type of elongated body. Appendage (*a*), unattached (*b*).

FIG. 6. Scalloped contact. Older mineral comprehended in the angles.

FIG. 7. Replaced mineral forms the angle (galena, *gn*).

FIG. 8. Replacing mineral forms the angle (chalcocite, *cc*).

FIG. 9. Replacing mineral forms the angle (tetrahedrite, *td*). One side straight, one curved.

FIG. 10. Filling mineral occupies the angle (chalcopyrite, *cp*).

evidence, varyingly reliable, as to the paragenesis of the two species. It may be said that generally the elongated mineral is the younger, because the alternative relation, in which the walls of the elongated body or vein are the younger, can be in many instances demonstrated as impossible. For this requires one of two

things: either a tabular or slowly tapering body developed in a liquid or gaseous medium and subsequently was filled in around by another mineral substance, or the original walls of such a formation were replaced by a new species without destroying it. The first case probably never happens in nature; we cannot conceive of a tabular body developing in a liquid or gaseous medium. The second case may well happen in nature. With regard to it more will be said later.

These bodies, distinguished by having two directions relatively great with respect to a third (one with respect to a second in polished-section), may be classified in various manners. The appendage type has already been mentioned. Belonging both to it and to the unattached type there are several kinds. There is the already-mentioned "wedge type," in which the walls, converging in one direction and diverging in the other, finally unite at one or both ends by rounding off. There is the "worm type," in which the walls, after maintaining parallelism for a considerable distance, finally bend toward one another and meet on the curve. There is the ellipsoid type in which the contact is always concave with respect to the inclosed species. These are represented in Figs. 3, 4, and 5.

It frequently happens that a tabular or elongated body displays over its entire length two or more of the above types. Probably a minority of instances is characterized by a limitation to one form.

ANGULAR CONTACTS.

Coming to contacts distinguished by the presence of angular vertices, or angular contacts, what can be said with respect to the evidence they yield for paragenesis? The angle-range involved varies between something less than 180° and something above 0°. The vertex may be formed, it is clear, either by the intersection of two curved lines, of two straight lines, or of one curved and one straight line. The first is certainly the commoner.

Confining our attention to all but small angles in the above range, it is evident that the mineral comprehended in the angle may be either younger or older. Assume a mineral crystallizing on the walls of an open space. If it is a species that possesses a

strong tendency to develop crystal facets when uninterfered with, it may well crystallize in euhedral or subhedral outlines. Should a later-depositing mineral now cover over these crystals, there will result a contact characterized by vertices of angles whose sides are straight lines. Should the earlier species not manifest a marked tendency to develop facets, its boundary, and hence its contact with the later mineral, will be most irregular, and will very likely include along with other geometrical patterns angles with curved sides.

Replacement will likewise produce an angular contact in which the species included in the angle is the older. As an instance of this may be mentioned the scalloped contact in which the mineral that is concave with respect to the scallops is the younger. In so far as this is so, the species included between the sides of the angle formed by adjacent scallops will be the older.

A mineral replacing another along its cleavage may exhibit angles in which either the older or the younger species is included between the two sides. Thus in Fig. 7, where chalcocite is replacing galena, the older mineral forms the angle. In Fig. 8, the younger forms it. Here the sides are straight lines, due to the presence of more than one cleavage direction. If only one cleavage is present, or the cleavage is prismatic, as, for example, in enargite, angles in the contact may exhibit sides of which one is straight, the other curved, *e.g.*, in Fig. 9, where tetrahedrite is replacing enargite.

In the above paragraph have been cited cases commonly occurring in nature, in which the younger of two species in metasomatic status occupies the space comprehended between the sides of the angle. Likewise, in filling relations, where one mineral coats or covers another, the angle may be occupied by the younger species. In Fig. 10, chalcopyrite is filling in between two intersecting pyrite grains. Or the sides of the angle may be curved and younger, as when any ragged surface with angular indentations is covered over by a later species.

Angular Contacts of Elongated Bodies.—This cursory survey of contacts characterized by the presence of angles indicates that, if the latter are medium or large, they tell nothing as to which

species is the younger. As the angle diminishes, however, we approach the case, considered under curved contacts, where a body or portion of a larger body *attains a length relatively great in proportion to its width.* With sufficient diminution in value, the body passes through the wedge-form into the roughly tabular or veinlike form. All the various geometrical shapes, mentioned under curved contacts, become possible. Indeed, as the proportion between length and width increases (that is, as the body becomes veinlike), the distinction between tabular bodies with curved outlines and those with angular outlines becomes inappreciable or negligible. Thus, for example, the worm veinlet with rounded end and the gradually tapering wedge-veinlet may appear so similar in polished-section that the two will be grouped as one type, particularly if the walls of each are parallel.

It is obvious that, as far as the geometrical pattern is concerned, the angular contact of a tabular body and its surrounding medium tells just as much about the relative ages of the two as the curved contact of the two in similar relations. The tabular body in either case would be called the younger, providing it were shown that the surrounding species had not replaced the original walls of the vein or elongated body.

PRE-WALL VEINS.

In paragenetical research, the writer believes that veins are too often considered the final authority to which the question of the age-relations of two contiguous species is referred. The investigator looks for veins, and, finding them, often unquestioningly places the vein mineral *after* the bordering mineral in sequence. It should be emphasized that veins are of two types, viz: (1) Veins later than their walls; (2) veins earlier than their walls.

The former is certainly common enough. The latter, the writer believes, is much commoner than is generally credited. And why should it not be common? Consider one mineral veining another. Is it not likely that in subsequent processes of mineralization the walls of that vein will be replaced, whereas the vein itself, on account of its differing chemical nature, either

wholly escapes replacement or is only partially replaced, the center of the vein or individual grains that constitute it surviving the effects of the solutions? If it wholly escapes replacement or corrosion by the later solutions, it is not clear that there is any way of detecting its pre-wall age. But in some instances certainly the later solutions leave their mark in the corrosive or dissolving effect on the vein itself or certain of its constituent grains.

The writer has seen photomicrographs appended to articles on the paragenesis of ores, in which the author unreservedly assigned a postwall age to the veinlets pictured. The appearances, however, as seen by the former, pointed to a very different paragenesis; namely, that the walls were the younger, and that the solutions which replaced those walls had subtracted everything pre-existing except the veins themselves, and even they had been nibbled and partially removed.

In certain Andean ores veinlets of pyrite may be seen in polished section cutting sphalerite and other sulphides. At first glance the veinlets would be called post-wall, but, if the individual pyrite grains are studied in detail, one comes to believe that they are early and belong to the main generation of iron sulphide. They differ strikingly from the pyrite veinlets, clearly of late origin, that traverse the ores, which show no marginal solution.

SUMMARY.

The relative ages of two mineral species in contact can be determined from the geometrical pattern only in case one species forms a body in the second sufficiently elongated to make it evident that the walls of that body existed prior to the deposition of the latter, that is, determined its localization. But before calling the species comprising the elongated body the younger of the two, it is further necessary to demonstrate that the original walls were not replaced by a third species. If there has been such replacement, then the walls are younger than the elongated body. The pre-wall age of the latter may often be detected by the presence of evidence of its partial solution and removal.

CERRO DE PASCO,
PERU.

HYDROTHERMAL ORIGIN OF THE BARITE IN ALABAMA.[1]

GEORGE I. ADAMS.

THE barite marketed from Alabama has come from concentrations in residual deposits in which it is commonly associated with red clays. The form of certain of the deposits is strongly suggestive of sink holes. In some of the pits, limestones and dolomites are exposed with barite occurring in them as irregular veins and replacements. Occasional aggregates of barite crystals with good faces indicate local deposition in cavities. Rounded barite nodules and crusts afford evidence of some solution and redeposition. The origin of the primary deposits, however, has not been satisfactorily explained; particularly the source of the barite, the agencies involved, and the time of deposition.

Recently the writer has found two deposits of barite in Alabama which constitute new types of occurrence in the state. Observations on some related metallic deposits lead him to the conclusion that the barite is of hydrothermal origin, that its source was from deep-seated magmas, and that it was deposited after the formation of the main structural features of the Appalachians.

In previous discussions it has been emphasized that the barite localities are in all cases near the contact of the Trenton limestones and the Knox dolomite,[2] and that these formations outcrop in narrow northeastward-trending bands, whose positions are determined by the folding and faulting that formed the Appalachians.[3]

The two deposits which the writer here reports as new modes

[1] Published with permission of the Geological Survey of Alabama in advance of a bulletin on the Barite Deposits of Alabama.

[2] Smith, Eugene A., and McCalley, Henry: Index to the Mineral Resources of Alabama. Geol. Surv. of Ala., Bull. 9, p. 62, 1904.

[3] Smith, Eugene A.: Statistics of the Mineral Production of Alabama for 1915. Geol. Surv. of Ala., Bull. 19, p. 12, 1917.

of occurrence in Alabama are situated near the border of Georgia. At one locality (number 8, Fig. 1) in the southeastern corner of Cherokee County, near the great overthrust fault by which the crystallines overrode the Paleozoics, there are veins in the shales of the Weisner formation, which is of Lower Cambrian Age. At the other locality (number 9, Fig. 1) in the southwestern

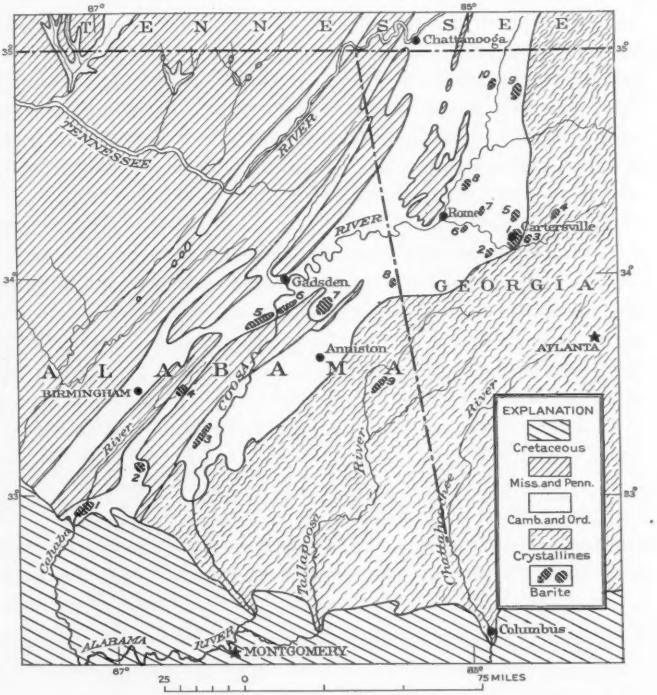


FIG. 1. Sketch map showing the positions and general geologic relations of the barite deposits in Alabama and Georgia.

part of Cleburne County, there are veins in Ashland schist. The Ashland schist is probably pre-Cambrian, but the veins are parallel with the schistosity which was induced during the Appalachian revolution, and the age of the veins is therefore as late as the close

of the Paleozoic. The veins at these localities are of only minor economic importance, being only twelve to perhaps eighteen inches thick, but they are of scientific interest. The barite veins in schists are in an area containing auriferous quartz veins and mica deposits and are presumably of hydrothermal origin. It is reasonable to suppose that the other deposits of barite in Alabama were formed at the same time and by the same agencies.

There is corroborative evidence that the barite in the dolomites and limestones is of hydrothermal origin. McCalley [4] reported that the barite near Tampa (now Angel), Alabama (locality 7, Fig. 1) carries some galena, perhaps argentiferous. It is well known that near this locality there are the "Old Lead Mines" at which a little digging was done during the Civil War. Sphalerite is associated with the galena at these pits. The ore has been reliably reported to carry silver, and Mr. Robert Hodges [5] has verified the presence of silver in galena from there. At Jamestown in Cherokee County, about 18 miles northeast of these old lead mines, there is also a lead prospect. The locality has long been known and was prospected in 1917. A little sphalerite is associated with the galena and the ore is said to carry about two ounces of silver to the ton.

Similarly, in the anticlinal valley in which the barite deposits (Nos. 4 and 5, Fig. 1) are shown, and about half way between them at Odenville, there is a shallow copper prospect which has not been previously reported. Small pieces showing malachite had been picked up in a field at various times for many years previous to the digging of a shallow shaft. Just how the copper occurs could not be seen since the opening had caved in, but there is limestone showing in the shaft and presumably the metallization, although perhaps of no economic importance, was hydrothermal.

The writer is indebted to the geological department of the T. C. I. Company of Birmingham for the information that Mr. Dougald Gordon found fluorite with the barite at locality number 4, Fig. 1, in Alabama. This association is good evidence of the origin which is here advocated.

[4] McCalley, Henry: Coosa Valley Report, Geol. Surv. of Ala., 1897, p. 715.

[5] Chemist of the Alabama Geological Survey.

In Alabama no igneous rocks are known to cut the unaltered Paleozoics. Mr. S. W. McCallie, State Geologist of Georgia, told the writer of a locality near Rome, Georgia, at which there is an intrusive in the Conasauga shales which escaped the notice of C. W. Hayes, who prepared the Rome Folio. In general appearance the intrusive resembles very closely a fine-grained dolomite, and such rocks, if they occur in Alabama, would not likely have been recognized in reconnaissance work. Because of the occurrence of an intrusive in Georgia well within the area of the Paleozoics, it is reasonable to suppose that magmatic solutions may have invaded the Paleozoics to the northwest of the great overthrust fault that separates them from the crystallines. That the galena and sphalerite at the "Old Lead Mines" near Angel, similar ore at the prospect near Jamestown, the copper at Odenville and the fluorite associated with barite at one locality in Alabama are of hydrothermal origin is a natural conclusion, and that the barite is of hydrothermal origin is a natural corollary.

Several authorities have studied the barite deposits of Georgia. Hull,[6] from whose report the positions of the barite deposits in Georgia, shown in Fig. 1, are taken, has written concerning them that:

> The origin of the barite may be generally and somewhat hypothetically stated as follows: barium originally in the feldspars and micas of the crystalline rocks was removed in solution by circulating meteoric and thermal waters, and carried from uncertain depths upward through channels made by faulting and fracturing in the earth's crust to limestone formations where favorable precipitating reactions caused the deposition of the barium sulphate, barite.

This statement in part follows the opinion of Hayes and Phalen,[7] that the original source of the barium is to be found in the silicates of the metal contained in the igneous rocks from which it is derived as the carbonate during the ordinary processes of weathering.

[6] Hull, J. P. D.: Report on the Barite Deposits of Georgia. Geol. Surv. of Ga., Bull. 36, p. 16, 1920.

[7] Hayes, C. W., and Phalen, W. C.: A Commercial Occurrence of Barite near Cartersville, Ga. U. S. Geol. Surv., Bull. 340, p. 458, 1908.

In discussing the barite deposits of Alabama, Grasty[8] emphasizes the importance of structural conditions and says that there is a general concordance of opinion that none of the deposits are of deep-seated origin and so are due to descending meteoric waters, but there is evidence that to some extent they are the result of thermal springs. This reference to thermal springs probably shows the influence of the writings of Hayes, who even in discussing the origin of bauxites in the region, appealed to the action of meteoric waters, which issued as springs that were probably thermal and may in some cases have formed geysers.

Watson and Grasty,[9] who have reviewed the barite deposits of the Appalachian States, do not make a definite statement as to the origin of the barite, although in many places they present information which implies a hydrothermal origin for important primary deposits.

In contrast with these ideas concerning the origin of barite in dolomites and limestones may be cited the opinion of Tarr,[10] who from his studies in Missouri, concludes that the barite of that state was deposited at shallow depths by ascending heated waters of igneous origin, and suggests that they were formed during deformation in Cretaceous time.

The opinion of the writer is that the barite deposits of Alabama are of mesothermal and epithermal origin and that the barium was brought up in emanations from magmas and deposited as veins and replacements, which were formed after the main Appalachian structure was developed at the close of the Paleozoic.

UNIVERSITY OF ALABAMA.
UNIVERSITY, ALA.

[8] Grasty, J. Sharshall: Barite Deposits of Alabama. The Tradesman, July 17, 1913, p. 35.

[9] Watson, Thomas L., and Grasty, J. Sharshall: Barite of the Appalachian States. Trans. A. I. M. E., vol. 51, pp. 515–559, 1915.

[10] Tarr, William Arthur: The Barite Deposits of Missouri. Univ. of Mo. Studies, vol. 3, no. 1, p. 100, 1917. See also ECON. GEOL., vol. 14, pp. 44–67, 1919.

A METHOD OF ILLUSTRATING THE MAGNIFICATION OF PHOTOMICROGRAPHS.

D. C. SHARPSTONE.

Photomicrographs of rock and ore specimens have come to play a common and important part in geologic and mining literature and reports. In many cases the important feature to be illustrated is the size of various units in the field, or the size and relationship of one unit to another. As a case in point, metallurgists and engineers commonly refer to photomicrographs of ores in order to understand and visualize the size and often complicated relationships of the ore mineral with the gangue, or if minerals of more than one metal occur, in economic quantities, their relationships with one another. These may be very useful in helping to determine whether the mineral or minerals may be separated from each other or from the gangue by mechanical methods and, if so, to what approximate size the ore will have to be ground to effect their freedom. Not infrequently, as work proceeds, it is found that, due to some structural characteristic of the ore or for some other reason, the results anticipated are not obtained through grinding. Under such circumstances samples of the heads, tailings, concentrates or other products may be examined microscopically in order to determine the degree of success or failure obtained, and photomicrographs of the salient features taken. Such a study is often of great aid in eliminating grinding and metallurgical difficulties. The recent study and treatment of many previously untreatable and complex ores, as the result of the development of flotation methods, has emphasized the value of the microscope and photomicrograph in this work and their use in this connection has now become widespread if not universal.

Again, in the study of metals, photomicrographs are widely used in illustrating microstructures, their characteristics, or their

sizes. In the microscopic examinations of sediments and mineral grains a study of grain sizes often forms a portion of the work, reports on which may be accompanied by photomicrographs.

Thus, in many photomicrographs, the illustration of unit sizes and size relationships is the principal consideration. The illustration of the magnification of these requires special consideration if the maximum value is to be obtained from them. The mere statement of their magnification or perhaps a line representing some unit of length drawn below them is not sufficient. In this form they may be visualized and interpreted only with difficulty and important features may easily be overlooked. Unfortunately, most photomicrographs are subject to these criticisms.

Hence, in order to overcome some of these criticisms, the writer has adopted and used, with considerable success, a simple scheme that illustrates magnifications graphically. By its use, the actual size of various units in the photomicrographic field may be observed directly. The method, hereafter described, divides the photograph into a series of squares, which represent the openings of standard screen meshes (or any other openings of known diameter) enlarged the same number of diameters as the specimen or field portrayed. Figs. 1 to 4 are examples of photomicrographs, of various magnifications, on which meshes have been superimposed.

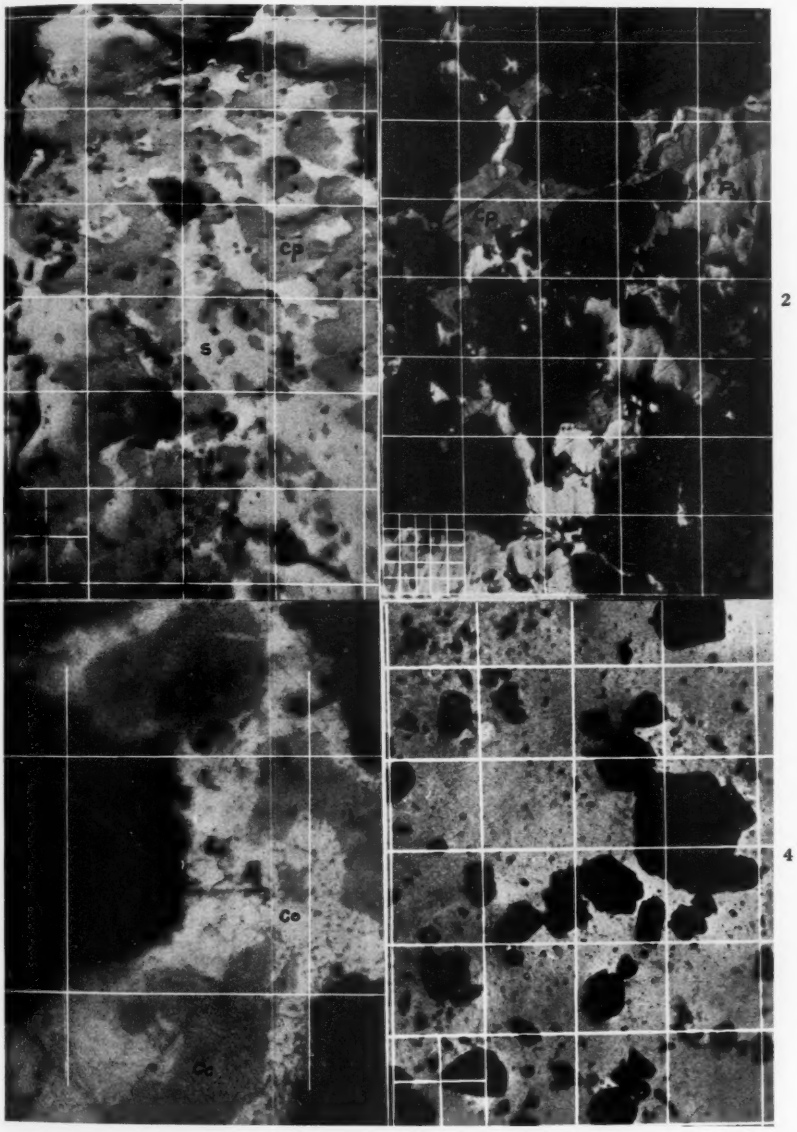
Such photographs illustrate advantageously the exact size of the minerals and textures that are present in the specimen portrayed. Likewise, if desired, the relative abundance of grains in any given field may easily be determined by inspection.

FIG. 1. Chalcopyrite (*Cp*), siegenite (*S*), and gangue (*G*). 100-mesh screen mask used with 200-mesh inset. × 100.

FIG. 2. Chalcopyrite (*Cp*), pyrrhotite (*Py*), gangue (*G*). 35-mesh screen mask used with 200-mesh inset. × 30.

FIG. 3. Covellite (*Co*), with chalcocite (*Cc*), and gangue (*G*). 200-mesh screen mask used. × 500.

FIG. 4. A sediment composed principally of highly altered feldspars and kaolin. 100-mesh screen mask used with 200-mesh inset. × 100.


1
2
3
4
Cp
S
Co
Co

Primarily the method has been used by the author to illustrate textural relationships and grain sizes in ores about to undergo metallurgical testing. Obviously, however, it may be applied over a broader and more diversified field.

Procedure.—Meshes are superimposed on photomicrographs by the use of celluloid masks, which are inserted between the photographic plate or film and the sensitized paper during the printing of the photomicrograph.

The type of celluloid selected for masks is important. Essentially, it should be clear and thin. Its thickness should never exceed 0.015 inches and should preferably be about 0.005 inches. Experience has proven ordinary filmpack cleaned in hypo to be entirely satisfactory. It is thin and is easily obtainable. A mask made from this material, if properly clamped to the photographic plate, will not rob the print of its clarity or detail, whereas thicker celluloid is likely to dull the print, destroying the sharp outlines and contrasts of the minerals. From the celluloid selected, pieces should be cut which conform exactly to the size of the photographic plates used.

A number of magnifications that will satisfy the requirements of the individual work should be selected, and in taking photomicrographs these magnifications should be used. For each of these a set of masks representing different screen meshes may be constructed. Magnifications of 30, 60, 100, 300 and 500 diameters will be found sufficient to satisfy most of the requirements which arise in the photography of mineral specimens. Care should be taken in selecting meshes for the masks that they be of large enough diameter to prevent the detail of the photograph from being obscured by an excess of lines. The following table lists the more convenient meshes to use with various magnifications, together with the size of their openings as they should appear on the mask when enlarged to correspond with the magnification:

TABLE 1.

CONVENIENT MESHES FOR USE WITH VARIOUS MAGNIFICATIONS.

Magnification	Suggested mesh and natural size of screen openings.	Size of openings on mask.
30 Diameters	20–0.833 m/m	24.99 millimeters.
	28–0.589 "	17.67 "
	35–0.417 "	12.51 "
60 Diameters	48–0.295 "	17.70 "
	65–0.208 "	21.48 "
100 "	100–0.147 "	14.70 "
300 "	200–0.074 "	22.20 "
500 "	200–0.074 "	37.00 "

Insets of finer meshes may be drawn in one corner of the mask when it is desired to illustrate a smaller mesh than is compatible with the magnification of the specimen (Figs. 1, 2, 4). India ink should be used in drawing the meshes on the masks and the lines should be made as fine as possible; a fine line is quite as effective as a heavy one and at the same time reduces to a minimum the possibility of obscuring detail in the photograph. It will be found that meshes can be more accurately drawn upon the masks if the mesh is first laid out to scale on drawing paper and then traced upon the celluloid mask. The space distance between lines is measured by scale. A 100-mesh screen has an opening of 0.147 millimeters. For a photograph enlarged 100 times the lines for this mesh would be 14.70 millimeters apart. For a magnification of 500 diameters the lines would be 73.5 millimeters apart.

Printing.—In printing a photomicrograph, a mask with mesh suitable to illustrate its important features and, of course, conforming to its magnification, should be chosen. The printer should securely fasten the mask with binding tape to the *sensitized side of the photographic plate* and proceed with the printing in the usual manner. To secure a successful print it is essential that the mask be placed on the sensitized side of the plate or film and further, that it fits *tightly* against it. The former produces a sharp reproduction of the lines on the print, which will otherwise

be lost; and the latter prevents blurring or loss of clarity in the photographs. Too much emphasis cannot be laid upon the importance of painstaking work during printing. It will be rewarded by excellent results.

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DISCUSSION AND COMMUNICATIONS

HYDROTHERMAL OXIDATION AND LEACHING EXPERIMENTS.

Sir:—This interesting paper by Mr. Gruner [1] contains valuable food for thought and speculation. Mr. Gruner's hydrothermal hypothesis, when supported by his laboratory experiments, seems to hold its own fairly well. However, there are a few points that do not seem to agree with the theory of hot ascending waters. The following comments are made particularly in connection with his treatment of the Gogebic Range. Mr. Gruner says of this district:

> The iron formation was highly shattered due to igneous activity. Dikes were intruded in the most shattered portions. The iron formation was heated, especially where steam and other gases accompanied the intrusions. Some of this steam may have been generated from water that happened to be in the formations. Only where the hydrogen formed in the oxidation of minerals could escape rapidly, oxidation of siderite, silicates, and magnetite proceeded and became almost complete. That was clearly above the dikes where the heat was most intense.

The average dike below an ore body on this range would seem too small to give off the quantities of steam and gases necessary to dissolve the huge volumes of silica removed, to say nothing of oxidizing a large part of the formation. The hydrothermal theory would be more plausible if a considerable flow of hot water and gases of magmatic origin came through the cracks in the formation before the dikes filled the cracks. Most of the dikes are relatively fine-grained, indicating that they cooled quickly. Once solidified, the discharge of water and gases must have ceased. One would conclude then, that the steam and gases could have been given off only for a short period of time,—not likely long enough to do all the leaching and oxidizing necessary.

[1] Gruner, J. W., ECON. GEOL., vol. 25, pp. 697–719; 837–867, 1930.

Mr. Gruner thinks that some of the steam may have come from water already in the formations, heated by the intrusives. This may be so, but where would the upward flow come from? A large flow over a considerable period of time is required.

We have always understood that the formations were lying in a more or less horizontal position when the dike intrusions occurred, and that the dikes followed vertical joint cracks. If this is true, and the hot waters and gases tend to go upward, would not the leaching and the ore bodies thus formed tend to be parallel to the dikes and as much on one side of the dike as the other? Most of our ore bodies have their long axis parallel to the formation, and usually there is ore on one side of the dike only. Apparently Mr. Gruner assumes that the iron formations were tilted to their present position when the dikes came in, and when he says "above the dikes" he refers to the dikes in their present inclination.

Most of our faulting, both longitudinal and across the formation, occurred after the dike intrusions had solidified. Therefore, the fault cracks would not be available for the hot ascending waters.

Our largest ore bodies are commonly found in the vicinity of one or more cross-faults, and chimneys of ore follow the fault planes. If the faults are later than the dikes, and the ore was concentrated along the fault planes after the faulting, then the hydrothermal activity must have also occurred after the faulting. We have been under the impression that most of the faulting took place around the time of the great post-Keweenawan folding, whereas the dikes were probably of pre-Keweenawan or early Keweenawan time.

The dikes in the iron formation are mostly altered and almost always highly altered in the vicinity of an ore body. Outside the iron formation the dikes are unaltered, as a rule. The hydrothermal hypothesis does not fully explain this condition. It is not likely that the gases given off by basic magmas would attack these same magmas and alter them only in the iron formation. We also find the larger dikes (the ones forming ore bodies) much

more altered on the upper side than in the middle and on the bottom.

Deep artesian circulation does not seem entirely impossible. Granting that there was not more than 1000 feet of vertical elevation between the inlet and the outlet of the circulating system, as Mr. Gruner supposes, the surface waters could still go down a mile or more and up through another channel to the outlet as long as the walls of the system were impervious. An outlet, say a broken up and fractured area at the bottom of the Lake Superior geosyncline, would probably satisfy the conditions. We have no proof that this is true, however, and it might not account for ground water circulation on other ranges.

The dissolving power of the leaching solutions must have been enormous. We have all seen large vugs, some entirely in the solid quartzite footwall, where the silica has been removed. Mr. Gruner's experiments show that hot water is many times more effective than cold water for dissolving silica. This makes one think that it might be possible for the slow-moving *descending* ground water to be so heated by the residual heat from the intrusive dikes as to make it a more active leaching agent. The heated water, rising to the outlet, would assist in the circulation. We know of hot artesian springs that apparently get their heat in this way. Whether enough heat remained in the ground after the formations were tilted to their present angle is hard to say.

Hot waters and gases coming from the intrusive dikes would seem to account for the phosphorus in the ore, as the dikes are relatively high in phosphorus. However, descending waters, altering the dikes and leaching them of phosphorus, might redeposit the phosphorus in the formation. We have some samples (not dike) that analyze 14 to 17 per cent. in phosphorus—probably nearly pure apatite. These samples were taken from very porous ground—apparently secondary filling material in the openings. Barite, a relatively insoluble mineral, has also been found filling vugs and water courses.

We also find water channels and vuggy openings in porous ground (not adjacent to a dike) that are colored brown and black

and look just as if they had been in a fire. The miner commonly says the ground was "burnt." This discoloration may be due to hydrothermal solutions.

The points mentioned above may be of only minor importance, not affecting the hypothesis as a whole. They may not be based on the correct geological interpretation of events. However, as far as the practical geology in the field goes, we must still look for the ore in troughs, in fractured zones and faulted areas.

Mr. Gruner has added materially to the information on this subject. Though we are not ready to accept his full hypothesis, it will assist in the search for further evidence.

LESLIE E. DICK.

MONTREAL MINING CO.,
MONTREAL, WIS.

HOW A GEOLOGICAL SURVEY SERVES THE STATE[1]

Sir: The Pennsylvania Geological Survey recently received an inquiry from a Western State as to the services which a State Geologist may render to or perform for the different Departments and Bureaus in a State Government.

The following paragraphs list a variety of cooperative services performed by the Pennsylvania Geological Survey for other divisions of the State Government.

Agriculture.—The code under which this Survey operates specifies that it shall study the distribution of soils. The soil and geologic maps of course are of benefit to the department. Entomologists in that department have discussed with members of the Survey the distribution of rock and soil in different areas with possible relation to fruit parasites, and similar problems. At the recent Farm Show, which is held annually in Harrisburg by this Department, the Geological Survey had an exhibit which attracted much attention.

Attorney General.—In a notable case, the legislature passed a law taxing anthracite, similar to a previous law which had been declared unconstitutional by the U. S. Supreme Court. The

[1] Published by permission of State Geologist of Pennsylvania.

State Geologist presented enough new facts to enable the Attorney General to successfully defend the act before all courts (three or four times before the U. S. Supreme Court).

Auditor General.—This department has been provided with data for the valuation of coal lands for corporation taxing purposes.

Banking.—The Securities Commission in the Department of Banking issues or refuses permits for the sale of stock in the State. Cases involving mineral land are referred to the Survey, and in more than one instance the Commission has been shown that permits should not be granted to issue stock because the purpose, according to the evidence, was to unload on the public land that did not have mineral deposits in the abundance represented, or the proposition seemed to be fraudulent. The Survey has also been of assistance in determining the validity of propositions outside of the State which were before the Securities Commission.

Barrier Pillar Board.—The State Geologist served as Secretary of this board and was mainly responsible for its conclusions and the writing of a new law.

Fish Commission.—The superintendent of this Commission applies to the Geological Survey for information on water supply for hatcheries and has brought to it problems regarding the pollution of the same.

Forests and Waters.—Besides engineering data for use in constructing maps of the State forests, this department has asked the assignment of a geologist to accompany parties of foresters whose interest might include relation of forests to forest soils and bedrock.

The Water Power and Resources Board in this department consults with the Geological Survey on engineering data regarding drainage areas and has asked the assignment of a geologist for the examination of foundations of dams being constructed under the supervision of this board.

Game Commission.—The Game Commission considering the purchase of a tract of land for a game refuge in the deed for which mineral rights were reserved asked the Geological Survey

to inspect the property to determine the probability of those rights being exercised.

Geographic Board.—The State Geologist has served as secretary of this board, which determines the spelling or form of geographic names in the State.

Giant Power Board.—The State Geologist has been an active member of this board, which published in 1925 an extensive report on the mass production and pooling of electric current.

Governor's Office.—The Governor has been furnished information on water power, coal land, etc., and under the direction of that office the Geological Survey prepared an exhibit at the Sesqui-Centennial at Philadelphia and is considering the proposition of an exhibit for the Century of Progress Exposition at Chicago. Laws affecting mineral lands have been referred by the Governor's office to the Survey for criticism, and references to minerals in speeches to be made by the Governor have been referred to the State Geologist.

Health.—In this department the Sanitary Water Board in particular has made use of the Survey to determine stream drainage areas, sources of contamination of the streams, and has had both office and field assistance in the problems of mine waste, phenol waste, and similar matters relating to the public water supply.

Highway.—The Survey has helped the Highway Department find stone for road building, even going so far one year as to have three parties in the field to locate quarry sites, determine the quality and quantity of the material available, quarrying conditions and transportation facilities at each quarry site.

Maps and Surveys Board.—The State Geologist has served as chairman of this board, which endeavors to coördinate the map requirements of the various departments and prevent duplication.

Military Affairs.—Besides furnishing engineering data the Geological Survey has assisted the department by examining a proposed site for a National Guard encampment of 10,000 acres to determine the adequacy of the water supply.

Mines.—Recent work with this department pertained to the formation of laws regarding barrier pillars, etc., in coal mines; the correlation of coal beds; aid in the preparation of a map of bituminous coal mines.

Property and Supplies.—Material has been collected and data prepared for the use of the engineers in this department engaged in the erection of public buildings.

Public Instruction.—Lectures have been given before Teachers' Institutes, articles written for school journals, and conferences held with officers of the department on science courses. Also the Survey has been called in conference on the development of additional underground water supply for State Teachers' Colleges.

Welfare.—An outstanding example of coöperation with this department was a field examination of a proposed site of 2,000 acres for a penitentiary, especially with relation to the availability on the site of building stone, brick clays and water supply. The Survey has advised on the source of water supply for hospitals, reformatories, and other institutions under the direction of this department.

Water supply, in each of the cases mentioned here, means underground water, and during the recent drought the Survey has been of material assistance, especially in a case last December where a State hospital with 185 beds all occupied was deprived of its water supply, which was bought from a nearby town, on twenty-four hours notice. A geologist was sent to the institution to determine the possibilities of developing a local supply by deep drilling and a well drilled on the selected site procured an adequate quantity of patable water.

It should be remembered that this is not a list of the uses of topographic and geologic maps, all of which are well-known to readers of Economic Geology, but a suggestion as to what a State Geologist can do for his fellow officials in a State Capitol.

R. W. STONE.
Assistant State Geologist.

HARRISBURG, PENNA.

REVIEWS

The Study of Rocks. By S. J. SHAND. Pp. xi + 224. Thos. Murby and Company, London, 1931. Price 6 s.

This little book is a discussion of rocks in as simple a way as possible, based on the author's classification of igneous rocks in which their chemical and their mineralogical characters are both made use of. After describing briefly the occurrence of eruptive rocks in the field, and their composition in terms of minerals, the author outlines the attempts made by various petrographers to classify them and concludes that the most satisfactory and the simplest scheme for this purpose is that proposed by himself a few years ago, based primarily on "the recognition of certain chemical incompatibilities among the rock-forming minerals." His classes, as is perhaps well known, are (I.) oversaturated rocks, containing free silica, (II.) saturated rocks, containing neither free silica nor unsaturated components; (III.) unsaturated rocks, consisting partly or wholly of unsaturated minerals, divided into a non-feldspathoidal and a feldspathoidal division. These groups are further subdivided into peraluminous, metaluminous, subaluminous and peralkaline rocks and again into eucrystalline (well crystallized) and dyscrystalline (ill crystallized) members, the line of division being "conveniently placed at the limit of unaided vision." These groups are then divided on the basis of the ratio of their light to dark components and finally on the ratio of orthoclase to albite and anorthite among their feldspathic components. Only 56 rock names are all that the author finds it necessary to use in carrying out his system. These he feels include practically all the rocks between which it is essential to distinguish.

He then follows with an application of his scheme to igneous rocks in general and classifies them pretty much as they have been classified heretofore. Perhaps his definitions of types are a little more precise than has heretofore been the case, but even in the new scheme there are gradational phases. The author's scheme undoubtedly has some advantages over older schemes, but whether it will be accepted by petrographers outside of the English-speaking countries is problematic. One feature that will tend to retard its adoption is the insistence of its author upon replacing well recognized terms by English ones. There seems to be no reason why anyone should prefer 'inset' to 'phenocryst,' when both express the same phenomenon and 'phenocryst' is in world-wide use. And 'dyscrystallized' is no better than cryptocrystalline.

The author's definition of metamorphic rocks is less precise than his definitions of igneous rock types, since he includes in his definition the limiting phrase that they are such as "can no longer be referred readily to their proper classes." He excludes entirely from the group such metasomatic products as phosphorite, formed by transformation of limestone, and of gypsum formed from anhydrite. Both rocks "can be placed without difficulty in their proper classes in the sedimentary division and it is better to leave them there"; why 'better' he does not state. The only rocks remaining in his metamorphic division are (1) mylonites, or crushed rocks, (2) hornstones, recrystallized by the action of heat, and (3) crystalline schists, crystallized under pressure. Hornstone is the general name given to all contact-metamorphosed rocks. The outstanding feature distinguishing them from crystalline schists is the "absence of any conspicuous parallelism of the minerals." "The crystalline schists are the products of recrystallization under directed pressure." They are divided according to the ratio of alumina to bases in their characteristic minerals into paraluminous, metaluminous, subaluminous and peralkaline gneisses and schists, but beyond this the classification is not along very clear or well-defined lines.

The book is a handy little volume that is very suggestive, but it is doubtful that it will supplement in general use such books as Harker's "Petrology for Students," or Hatch and Rastall's "Sedimentary Rocks." It is, however, well worth reading.

W. S. BAYLEY.

Principles and Practice of Geophysical Prospecting. By BROUGHTON-EDGE, A. D., AND LABY, T. H. Demy 4to, pp. xiv + 380, illus. 261. Cambridge University Press, 1931.

The Imperial Geophysical Experimental Survey under the directorship of Mr. Broughton-Edge had the task of testing out the geophysical methods of prospecting. The electric, magnetic, and gravimetric methods and to a less extent the seismic method, were tried out at fifteen different localities widely scattered over the six Australian States. The surveys were very largely over known deposits of sulphides and other ores, graphite and lignite, saline waters, and geologic structure. To avoid the necessity of respecting confidential communications of theory and practice, and to maintain freedom of speech in reporting conclusions, entangling alliances with commercial geophysicists were avoided. The handicap was thereby incurred that the personnel did not include well experienced practical geophysicists in the gravimetric, magnetic, and seismic methods. Some of the instruments, as for example, the torsion balances, were not standard. The Imperial Geophysical Experimental Survey seems to have maintained a high standard of work and to have done a most excellent and

creditable job. The present book is the formal report of the investigations of the Imperial Geophysical Experimental Survey.

The report consists of two parts: the first gives an elementary exposition of the several methods and a simple presentation of the results of the various individual surveys which were made by the Imperial Geophysical Experimental Survey; the second part gives a much more technical discussion of the field procedure, design, and behavior of the apparatus, interpretation of the results, fundamental principles of the methods, and various problems in regard to the theory and practice of applied geophysics. This book is not simply a formal report, but in a way is a text book of geophysics. The reviewer warmly commends it to all geophysicists and to all geologists and engineers who are closely interested in applied geophysics.

DONALD C. BARTON.

Physics of the Earth; Part I., Volcanology, by Subcommittee on Volcanology, A. L. DAY, Chairman. National Research Council, Bull. 77. Pp. 77. National Academy of Science, Washington, 1931.

This part contains: Introduction by A. L. Day; Chap. I., Volcanoes, Their Activity and Their Causes, by K. Sapper; II., Present Condition and Future of Volcanology, by I. Friedlaender; III., Mechanism of Volcanoes, by T. A. Jagger.

Part II. (See review, p. 553.)

Part III., Meteorology, by Subcommittee on Meteorology, H. H. KIMBALL, Chairman. National Research Council, Bull. 79. Pp. 289.

This book is in six chapters, as follows: Introduction, Development of the Science of Meteorology, by H. H. Kimball; Chap. I., The Atmosphere, by W. J. Humphreys; II., Meteorological Data and Changes, by A. J. Henry; III., Solar Radiation, by H. H. Kimball; IV., Meteorology of the Free Atmosphere, by W. R. Gregg, L. T. Samuels, W. R. Stevens; V., Dynamic Meteorology, by H. C. Willett; VI., Physical Basis of Weather Forecasting, by R. H. Weightman.

These three volumes are the first of nine on the "Physics of the Earth," designed "to give the reader, presumably a scientist but not a specialist in the subject, an idea of the present status together with a forward-looking summary of its problems." These first volumes seem to have achieved their purpose.

Physics of the Earth: Part IV, The Age of the Earth. Nat. Research Council, Bull. 80. Pp. v + 487. National Academy of Science, Washington, 1931. Price, $5.00.

The series of reports on the Physics of the Earth, of which this is the fourth, is a great boon to geologists, physicists and astronomers, as it furnishes in an authoritative and readable form a summary of the knowledge we now have of the character of the Earth as an entity. The volume dealing with the figure of the Earth has already been noticed in this journal (Vol. XXVI, No. 5, p. 553). The volumes on Volcanology (Bull. No. 77) and Meteorology (Bull. 79) appeared some months ago. The present volume discusses the conclusions reached as to the age of the Earth based (1) on a study of the sedimentary deposits (by C. Schuchert), (2) on a study of the salt content of the ocean (by A. Knopp), (3) on a study of the radioactivity of minerals in the rocks (by A. F. Kovarik and A. Holmes), and (4) upon the results of astronomical observations (by E. W. Brown). The fourth method is lacking in definiteness, but the others have yielded results that are well known. The value of the present volume lies in the fact that it gives a brief history of the development of each method, a summary discussion of each, and a statement of the conclusions reached by the students who have most critically examined them. In short, we have in the volume a dispassionate and authoritative summary of about all that is known at the present time about the age of the Earth, accompanied by valuable bibliographies.

Naturally, the most interesting part of the report deals with the results of the study of radioactivity, which covers about 390 pages. This, moreover, is much more than the ordinary summary. It is, rather, a fairly thoroughgoing discussion that deals not only with the age of the Earth as determined from radioactive minerals, but also with the principles underlying radioactivity, and the methods of determining the age of radioactive minerals of critical significance. The bibliography of this section is especially rich. It contains about 750 items. It is impossible to give in this place even an outline of the contents of the section. It must suffice to state that the result of the study indicates the Earth to be at least 2,000 million years old.

W. S. BAYLEY.

A Practical Handbook of Water Supply. By FRANK DIXEY. Pp. xxviii + 571, figs. 133, maps 6. Thos. Murby & Co., London, 1931. Price 21s.

The publisher's announcement of Dr. Dixey's book gives an excellent statement of its point of view in discussing water supplies in a dry country. "The practical aspect of retaining or recovering water is treated mainly from the point of view of those who, though inexperienced in such work, are faced with the necessity of developing small water supplies for European and native settlements; but the geological aspect of water supply is treated in sufficient detail to make the book

distinctly useful to engineers and others upon whom falls the task of carrying the larger water supply schemes into effect." The book measures up to the outline suggested. It is a clearly written and well illustrated volume containing nearly all the information needed by one who seeks water, and after finding it, wants to know how to secure and conserve it, and by him who merely desires to store periodic supplies for use in time of water scarcity. The author discusses the water resources of a region, the preparation of catchment and storage structures, the building of dams of many different kinds, the origin and distribution of ground water, the method made use of to get it to the surface, the excavation and drilling of wells and their care, the use and construction of infiltration tunnels and subsurface dams, and many other topics that are of interest to the man who wishes to know as much as possible about water in a dry country.

One chapter is devoted to the quality of water and its purification, under the latter of which topics are described a number of simple ways to render impure water drinkable. For him who desires to go a little further into the subjects discussed, there is provided at the end of each chapter a number of significant references.

The last 70 pages are devoted to a description of the geology and water supply conditions in Southern, Eastern, and Central Africa, illustrated by geological maps of Nyassaland, Tanganyika, Kenya and Uganda.

The book contains a vast amount of information of a very practical kind on water supplies in general.

W. S. BAYLEY.

The Mines Handbook, vol. XVIII., 1931 issue. In two volumes. L. H. RAND AND E. B. STURGIS, editors. Pp. 2870 + 51 + 66. Mines Inform. Bureau, Suffern, N. Y. Price, $25.00.

This well-known publication pertaining to the metal industry of the Western Hemisphere has been considerably enlarged and revised in this issue. Part I., with 2026 + 51 pages, relates to the United States. Part II. deals with the other countries of the Western Hemisphere. The first 60 pages include a glossary, mineralogy, and statistics of the metals, giving production, consumption, prices, occurrence, and uses. The remainder is devoted to the usual annotations of all mining companies, arranged according to states and countries. It is up to date, well arranged, and appears to be comprehensive. It is invaluable to all who have to refer to data regarding mining companies.

Copies of books mentioned under "Reviews" or under our "New Book List" (see advertisement page) may be purchased through our Journal Bookshop by writing to W. S. Bayley, University of Illinois, Urbana, Ill.

BOOKS RECEIVED.

Grundprobleme der Geologie. By SERGE VON BUBNOFF. Pp. 237, figs. 49. Gebrüder Borntraeger, Berlin, 1931. Price, 11.60 M. Deals with fundamental problems of rock formation, geologic time, continents, geosynclines, mountains, the interior of the earth.

Deutsches Erdöl. By A. BENTZ, R. HERRMANN, A. KRAISS, O. STUTZER. Pp. 150, figs. 27. F. Enke, Stuttgart, 1931. Price, 18 M. A detailed and careful discussion of individual oil details, concisely treated, in a small book prohibitively priced at $4.50 unbound.

The Physical Chemistry of the Magmatic Differentiation of Igneous Rocks. Pt. III, second half. By J. H. L. VOGT. Pp. 242, figs. 77. Norske Vidensk.-Akad., Oslo, 1931. This valuable monograph deals with the evolution of granite, quartz, porphyry, pegmatites; their differentiation, crystallization, texture, melting points, etc., and with the genesis of granites.

Berggrunden inom Malmtrakten Kiruna-Gällivare-Pajala. By PER GEIJER. (Pre-Cambrian Geology of the Iron-bearing Region Kiruna-Gällivare-Pajala). Pp. 184, figs. 61, map. English summary (41 pp.). Stockholm, 1931. Price, 4 Kr.

Quicksilver. By C. N. SCHUETTE. Pp. 168, figs. 56. U. S. Bureau of Mines, Bull. 335, 1931. Price, 45 cts. Occurrence, development, mining, metallurgy, uses, economics, distribution.

Oil and Gas in the Bluegrass Region of Kentucky. By W. R. JILLSON. Pp. 123, illus. Kentucky Geol. Survey, Frankfort, 1931.

List of Publications on the Geology of Illinois, with index. Pp. 75. State Geological Survey, Urbana, Illinois, May, 1931.

The Fluorspar Deposits of Hardin and Pope Counties, Illinois. By E. S. BASTIN. Pp. 116, pls. 9, figs. 48. Illinois State Geol. Survey Bull. 58. Urbana, 1931. Detailed discussion of the deposits according to types; detailed mineralogy; postulates derivation from basic magmas; mining data.

Ueber die Bewertung von natürlichen Gesteinen für bautechnische Zwecke. By ROMAN GRENGG. Pp. 64, figs. 8. Abh zur prakt. Geol. und Bergw. Bd. 15, Wilhelm Knapp, Halle, 1928. Price, 6.60 M.

Mexico: A Study of Two Americas. By STUART CHASE. Pp. 338. Artistically illustrated by Diego Rivera. Macmillan Company, New York, 1931. Price, $3.00. A finely written story in popular style dealing with the history, geography, people, customs, and economic conditions of Mexico, and the contrast of machineless vs. machine age men.

Invaluable to geologists and engineers who deal with Mexico and of great interest to the general reader.

Informe de la Dirección General de Minas y Petróleo (Bolivia), 1930. J. M. REYES, Director General. Pp. 230. La Paz, 1931. Annual report of departmental activities, statistics, and progress of mining.

The Geology of the Country Surrounding NKandhla, Natal. By A. L. DU TOIT. Pp. 111, figs. 11, pls. 3. Geol. Survey, Union of So. Africa, Sheet 109. Pretoria, 1931. Price, 5s, incl. map.

Thirty-Second Annual Report, Mining Industry of Idaho, 1930. By STEWART CAMPBELL. Pp. 308, index. Moscow, Idaho, 1931. General review; mineral resources; activities and mining companies of each county.

Geology and Mineral Resources of Hardin County, Tennessee. By W. B. JEWELL. Pp. 117, pls. 9, figs. 3. Div. of Geology, State of Tenn., Bull. 37, Nashville, 1931. General geology; iron ore, manganese, and miscellaneous non-metallics.

References to Occurrences of Economic Minerals in the Gold Coast, recorded in annual reports of the Director, Geological Survey. By A. E. KITSON AND W. J. FELTON. Pp. 35. Gold Coast Geol. Survey, Bull. 5, 1931. Price, 1s.

Minerals of Concentrates from Stream Gravels, Soils and Crushed Rocks of the Gold Coast (with map). By A. E. KITSON AND W. J. FELTON. Pp. 50. Gold Coast Geol. Survey, Bull. 6, 1931. Price, 1s.

Oil and Gas Map of New Mexico. Compiled by DEAN E. WINCHESTER. Scale 1 : 1 million. New Mex. State Bur. Mines and Miner., Socorro. Price, paper $1.00, cloth $1.50. Shows (in two colors) some 200 anticlinal structures and 1000 wildcat wells with data, also oil and gas fields, pipe lines and plants.

Tanganyika Territory Geol. Survey, Ann. Rept. 1929. By E. O. TEALE, Director. Pp. 60, figs. 9. Dar-es-Salaam, 1930. Price, 4s. Departmental and staff activities; ten short reports on geological field work by members of the staff, and ten reports on water supply investigations.

Some Salt Lakes of the Northern Rift Zone (Tanganyika). By DOUGLAS ORR AND D. R. GRANTHAM. Pp. 23, maps 3. Geol. Survey Tang. Terr., Short Paper No. 8. Dar-es-Salaam, 1931. Price, 4s. Geology, occurrence, origin, and economic possibilities of salt deposits in Lakes Basoda, Balangda, Balangdalalu, Singida, and Eyasi.

SCIENTIFIC NOTES AND NEWS

H. G. Ferguson, of the U. S. Geological Survey, spent the summer in Washington and devoted most of his time to preparations for the International Geological Congress excursions and the editing of manuscripts for use in the Excursion Guidebooks.

A. L. Du Toit, of DeBeers Consolidated, South Africa, was recently borrowed by the Imperial Government for several months of field work in the Kalahari, in the northern part of the Union of South Africa. He has now been transferred to Johannesburg, where his address will be P. O. Box 4565. He is spending October and November in examination of some of the recent discoveries of kimberlite in Uganda and Kenya.

Alpheus Williams, General Manager, DeBeers Consolidated, Kimberley, South Africa, has been promoted by King George to the grade of Knight of Justice of the Venerable Order of St. John. The many geologists to whom Mr. Williams was so gracious a host at the time of the South African Geologic Congress will be pleased to learn of this recognition.

Waldemar Lindgren has returned to Cambridge after a long holiday in Europe.

D. F. Hewett, of the U. S. Geological Survey, has just returned from a long field season in Alaska.

Myron T. Walker, of the U. S. Tariff Commission, has been collecting data in Arizona and New Mexico on copper production costs, for inclusion in a report to be presented to Congress in December.

E. R. Lilley has returned to this country after a year spent in studying the mineral resource problems of Europe under a grant from the Guggenheim Foundation.

Robert W. Karpinski has returned from France, where he has been studying mining geology at Nancy.

E. B. Holt, formerly of Sonora, Mexico, is engaged in the development of a group of gold mines in southwestern Durango.

Frank H. Skeels is re-opening the Boise-Rochester gold mine at Atlanta, Idaho, for the St. Joseph Lead Company.

Enoch Perkins, who has been spending some time in New Caledonia, reports that chrome mining is still being carried on although most of the ore is being stocked.

The third printed report of the Committee on Sedimentation of the Division of Geology and Geography, National Research Council, for the year 1929–1930, is now ready for distribution as No. 98, Reprint and Circular Series, and may be obtained by sending one dollar to the Publication Office, National Research Council, Washington, D. C.

At the meeting of the Washington Academy of Sciences on October 26, Dr. Willem de Sitter, Director of the Observatory at Leyden, Holland, delivered an address on the Origin of the Planetary System.

The Geological Society of America will hold its mid-winter meeting at Tulsa, Oklahoma, December 29–31, 1931. This is the first meeting of this society to be held in the Southwest for many years.

The Society of Economic Geologists will hold its annual meeting December 29–31 in conjunction with the Geological Society of America meeting, at Tulsa, Oklahoma.

The American Institute of Mining and Metallurgical Engineers held its Fall meeting at Joplin, Missouri, September 28–30. The Society of Economic Geologists took part in the meeting and excursions but did not offer an independent program. Three papers were given on the topic "Geology and Ore Deposits of the Mississippi Valley Type," by H. A. Buehler; W. M. Hayward and W. H. Triplett; and George M. Fowler and J. P. Lyden. C. K. Leith discussed "Problems of Mineral Supplies." Several papers were given on "Mining Congress Day," two particularly thoughtful ones being "The Mining Outlook," by R. E. Tally, and "Stabilizing Our Natural Resources Industries," by F. H. Probert. A field excursion took in the mining field nearby. All who attended found it a profitable and extremely interesting meeting.

Joseph D. Tower, Harvard, 1921, mining geologist, was drowned in the Rio Grande River on August 23. He was the son of Joseph T. Tower of Milbrook, New York, and of the fourth generation of a mining family. He had many mining interests in Canada and the United States.

G. C. Mackenzie, Secretary of the Canadian Mining Institute, died suddenly on August 22 while on a vacation at Bark Lake, Quebec.

The recently published 20-volume index (336 pages) of ECONOMIC GEOLOGY for 1905 to 1925, compiled by J. M. Nickles, may be obtained for $3.00 from W. S. Bayley, University of Illinois, Urbana, Ill.